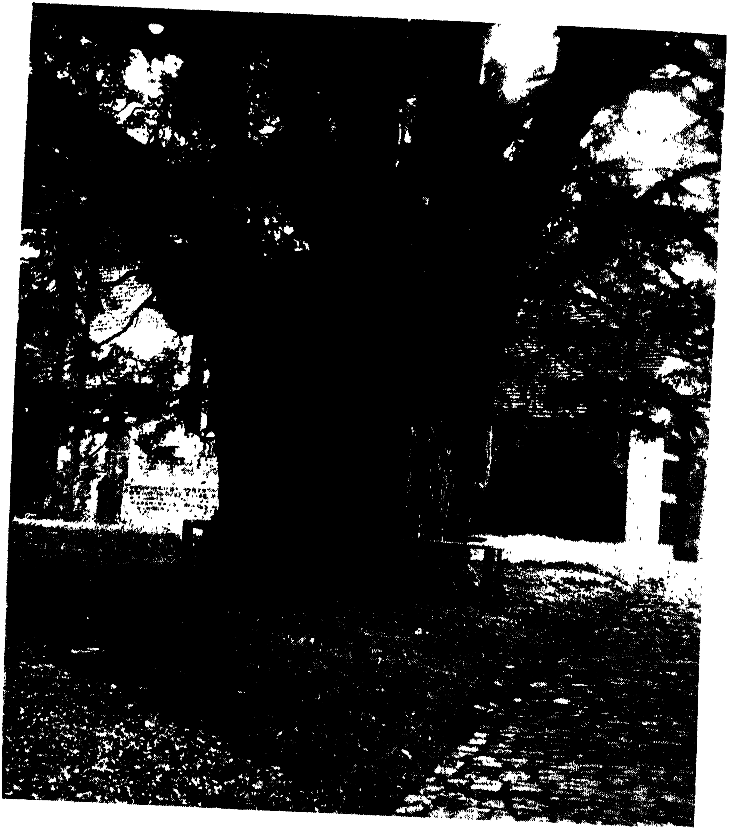
A MODERN BIOLOGY



[Photo: R. D. G.]

One of the oldest living things in England: the Selborne Yew, about which Gilbert White wrote in 1789. It is probably over six hundred years old.

A MODERN BIOLOGY

by

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To

L. M. H. E. B. G.

E. W. H. F. E. G.

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FOREWORD

It is likely that many years will pass before we gather the full harvest of the three great Reports of the Consultative Committee of the Board of Education, the Report on the Education of the Adolescent, the Report on the Junior School, the Report on the Infant School. They involve widespread administrative changes in education, radical changes in the function and form of the school, a fresh consideration of the content of the school curriculum and of teaching methods; but above all they are shot through with the implication that what is required is a fresh approach to and understanding of the child. These Reports are a charter, not, as has been the case previously, for selected groups of children, but for all children and young adolescents.

The great change that has been coming over our thought of education is that it is the whole child with whom we are concerned. It is not enough to perfect the teaching of each subject of the school curriculum or even to fit the curriculum to the child. We now recognise, less no doubt in practice than in theory, that we must educate the child towards no narrow end—towards passing an examination, towards earning a living—but towards the living of its life, its personal life, and this life in relation to the community.

This fresh conception of education as applied to all children involves a profound change in our sense of values in education. What were considered, when a narrow view held sway, as educational frills and fads, are now recognised as fundamental. This applies to physical education in its many newer aspects, to the arts and crafts as media for creative expression, to the place of the teaching throughout the school life of the child of elementary science based upon biology. Behind and largely determining this change in values is the growing understanding that the process of education itself is a biological process, that it must be concerned with the child throughout the developmental period from infancy up to eighteen years.

Such a biological approach must necessarily take cognisance of the whole child—its physical, intellectual and emotional life—and of the whole life of the child—its home, school, social and industrial life.

But if the education of the child for life is a biological process, the child must, from its earliest days, learn from the life by which in its many forms it is surrounded. It may sound extravagant to say that biology should be taught throughout the school life of the child, but that is only because we have become accustomed to too narrow a view of the purpose and content of such teaching. We are apt to think of biology as a compound of botany and zoology as these are now taught to older children largely from an examination point of view. This, however, gives an entirely misleading picture of what biology should mean in the school curriculum. What it should mean, and how it should be interpreted in the different stages of the child's school life, we are now gradually working out. The beginnings are already to be found in the Junior School in which the study of plant and animal life around the child, though usually known as Nature Study, is true biological teaching.

An important point to keep clear is that the teaching of biology should not be thought of in a water-tight compartment apart from the teaching of chemistry and physics. What is needed is a fresh interpretation of the teaching of elementary science throughout the child's school life.. The teaching of chemistry and physics has been standardised through much practical experience but, however well these subjects are taught, they alone are quite unable to bring to the child all that it should get out of the teaching of science. The task to-day, especially for the senior boy or girl in whatever type of school, is for each school to work out the teaching of science from a fresh angle.

Naturally any science course for boys and girls should include some teaching on matters of health, but there can be no sound and lasting health education which is not based upon a foundation of biology. The teaching of "physiology and hygiene" has proved inadequate; there was no foundation upon which to base the physiology taught. The introduction

of biology as a school subject makes possible a great advance in education in matters affecting both personal and communal health and their interaction the one upon the other. Children in their early teens are interested in the working of their own bodies, and human biology will necessarily form an integral part of any course in general biology.

It is this need for a sound foundation upon which to base the education of the adolescent in the art of living the healthful life that has been kept in view throughout this book. We have yet much to learn in regard both to the content and the presentation of a course in biology as part of an elementary science course suited to the needs of senior boys and girls. Towards this end this book makes a notable contribution.

R. H. CROWLEY

January 1936

INTRODUCTION

It is becoming increasingly recognised that biology is more than a mere study of a number of "types" of living things, however wide their range may be: it is the study of life itself. On the other hand, we cannot study life except as it is manifested in living organisms and so we cannot abandon the "type system" altogether. For our own part, we believe that by far the best way in which our pupils can make the acquaintance of living things is through the study of nature, for in this way they become familiar with them as living entities functioning in their natural environment. Once they have that knowledge they gradually become curious as to how living organisms "work" and so are ready to pass on to the study of the life which is common to them all.

It is for this second phase of the biology course that we have written this book. We have laid the main stress on function rather than on structure and have thus been able to take a broad biological basis and to stress the essential unity of the life-processes. We have tried to illustrate these processes from a wide range both of animals and plants—and have not hesitated to include man as one living thing among many such, since in many ways the human body is the organism most familiar to our pupils. In this way, we have allowed man to take his "natural" place in the biology course and have been able to deal with many points which we regard as important in connection with human physiology and hygiene.

Since we have assumed that pupils using this book will have completed a course of nature study, we have deliberately excluded detailed descriptions and illustrations of such material: the pupils should make their *own* observations and drawings without the aid of any textbook. Thus, for example, while we have dealt in their appropriate places with the rôle of cotyledons and endosperm in the seed and with the significance of the pupal stage in the development of insects, we have not dealt with the details of germination or of insect

life-histories. Again, we have not dealt with the ecological aspect of biology—for ecological principles can best be developed by each individual teacher from the materials to hand in his own locality.

Though this book was practically finished before the Science Masters' Association syllabus in biology was published, it would appear that—except for the details mentioned above—we have covered that syllabus both in content and in outlook. We believe also that we have covered the ground suggested as the minimum requirements in biology and health teaching in the Hadow Report.

In conclusion, we offer our thanks to the following friends for the very valuable help they have given us in the preparation of the book:

To Professor A. A. Cock, to whose inspiration the book owes its origin;

To Dr R. H. Crowley, for the Foreword;

To Mrs E. J. Holmes and Mr W. R. B. Brooks who read the proofs and made many valuable suggestions, and to Mr G. R. Carter for his help with Chapter IV;

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To Lady Mellanby, Professors F. E. Lloyd, J. G. Coulson and C. W. Lowe, Dr J. Gray, Messrs W. A. Ashby, J. R. van Haarlem, L. Hogben, and J. H. Whyte, Messrs F. E. Becker and Sons, Messrs A. Wander and Co., and the proprietors of Gough's Caves, Cheddar, who have given us photographs for use as plates.

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Messrs G. Newnes and Sons (Thomson, *The Outline of Science*);

Messrs Ivor Nicholson and Watson (Wilson, *Life of the Shore and Shallow Sea*);

Messrs Oliver and Boyd (Hogben, *Pigmentary Effector Systems*);

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Messrs P. G. 'Espinasse, Niall Rankin and D. P. Wilson.

E. J. H.
R. D. G.

September 1936

SECOND AND THIRD EDITIONS

A number of minor alterations to text and figures have been made, chiefly in order to bring them more closely into line with changes in certain examination syllabuses and recent advances in scientific discovery. Our thanks are due to those teachers who have made suggestions. To avoid confusion, the original numbering of the diagrams has been preserved.

E. J. H.
R. D. G.

September 1939
July 1946

The authors' chief difficulty in writing this book has been to choose just what material should be included and what material—much of it intensely interesting—should be excluded. If this book interests you, you will probably also be interested in the following books:

Fox: *Biology*. Camb. Univ. Press.
Wells and Huxley: *The Science of Life*. Cassell.
Shipley: *Life*. Camb. Univ. Press.
Seward: *Plants*. Camb. Univ. Press.
Peattie: *Cargoes and Harvests*. Appleton.
Salisbury: *The Living Garden*. Bell.
Haldane and Huxley: *Animal Biology*. Oxford Univ. Press.
Huxley: *Essays in Popular Science*. Chatto and Windus.
Russell: *The Behaviour of Animals*. Arnold.
Hill: *Living Machinery*. Bell.
Plimmer: *Food, Health, Vitamins*. Longmans, Green.
Harris: *Vitamins*. Camb. Univ. Press.
Haldane: *Possible Worlds*. Chatto and Windus.
Singer: *The Discovery of the Circulation of the Blood*. Bell.
Russell and Yonge: *The Seas*. Warne.
Baker and Haldane: *Biology in Everyday Life*. Allen and Unwin.
Waddington: *How Animals Develop*. Allen and Unwin.
Cullis and Bond: *The Body and its Health*. Nicholson and Watson.
Buchsbaum: *Animals without Backbones*. Chicago Univ. Press (Camb. Univ. Press).

CHAPTER I

LIVING THINGS AND THEIR PARTS

Except for certain microscopic forms of life for which it is very difficult to draw distinctions, all living things are either plants or animals. Those which are large enough to be seen easily with the naked eye are composed of various parts or *organs* which together make the whole *organism* and we find that each organ has its own particular job or *function* to perform.

You will probably be surprised to find that, in spite of the apparently great differences between plants and animals, the life processes are essentially the same in all living things. Thus they all need much the same foods, they all need energy, they all have waste products to excrete and they all have powers of responding to stimuli, of reproduction, growth and healing. Thus, while they show a variety of structure, they also show close similarities in function, and it is on these similarities that we shall base our study of Biology—the science of life.

In this chapter we shall study one or two typical plants and animals, and in succeeding chapters we shall discuss the various life processes.

TWO TYPICAL PLANTS

It is easy to talk of typical plants, but it is less easy to select them, for we are all familiar in a general way with a great variety of plants. We are agreed in calling the ferns and aspidistras of our homes, the elms that line our more pleasant streets and the grass of the football field "plants". Botanists (who spend their lives studying plants) agree that mushrooms and toadstools, mosses, seaweeds and the yeast that leavens our bread must also be included. The choice becomes more difficult! Let us limit the field for a moment by proposing to select as a first example a *flowering plant* (for we all know that while many plants flower there are some that seem never to

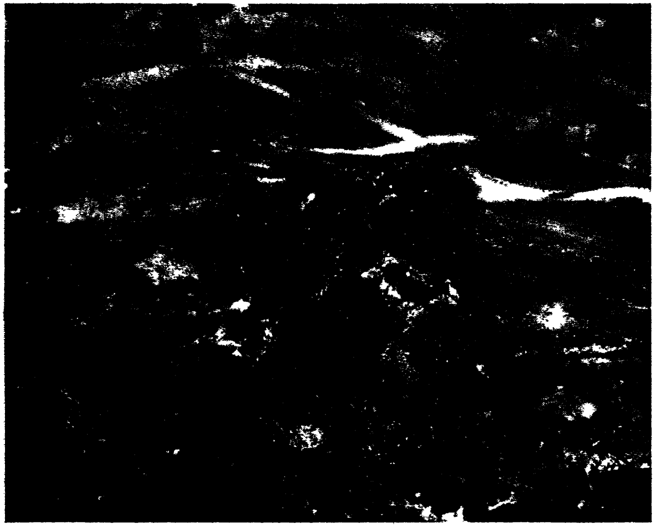

Fig. 1. Seaweeds ("algae") growing on a rock between tide levels. ($\times \frac{1}{10}$.)

Fig. 2. Moss on the trunk of a birch tree. ($\times \frac{1}{5}$.)

[Photos: R.D.G.]

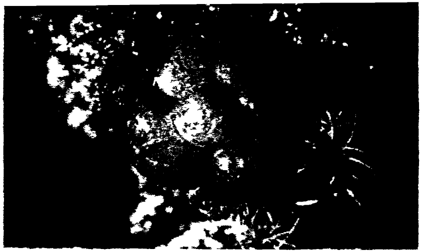

Fig. 3. Colonies of *Nostoc* (a "blue-green alga"): each colony is composed of hundreds of threads of the alga embedded in jelly

Fig 4. Moulds ("fungi") growing on cheese

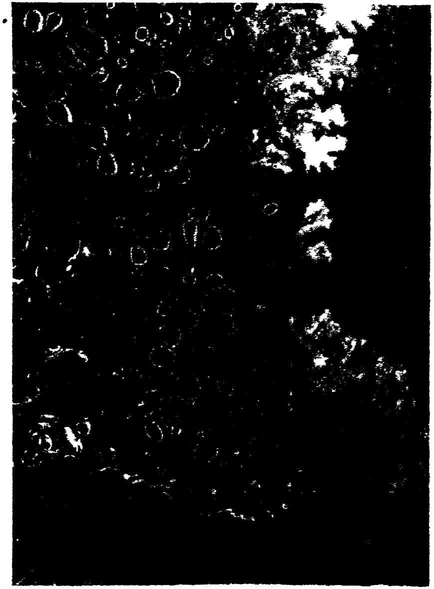

Fig 5 A lichen growing on a rock. (×2.)

SOME "LOWER" PLANTS

[Photos: R.D.G.]

bear flowers—of these we shall have more to say in later chapters). Even here we meet with great variety. The trees, however, are most impressive, so we will start with a familiar type such as the cherry.

The Cherry Tree

Each tree is a unit in itself—as nearly independent of its neighbours as a living thing may be. Each has an individuality of its own (so that no two cherry trees are exactly alike)

Fig. 6. A cherry orchard in Ontario. [Photo: J. R. van Haarlem.]

but all cherry trees have so much in common that we are unlikely to confuse them with oaks or with maples (i.e. with other kinds of trees). One rather important thing we recognise is that our cherry trees vary a great deal in size. While very small ones bear no flowers or fruit, the larger ones do—and continue to flower and fruit and also to grow for many years.

Though each tree, as we have seen, is a unit—an individual —it is a unit with very different parts that together constitute

the whole. Without hesitation we can name most of these parts: roots, trunk, branches, twigs, leaves, flowers, fruit. It is obvious that all the parts are related and together make the tree; and it is equally obvious that some, at least, of the parts have particular functions to perform. Let us consider them. for the sake of convenience, in turn.

How seldom we see a *root*! That in itself is a pointer—the root is usually underground. Its obvious function is to anchor

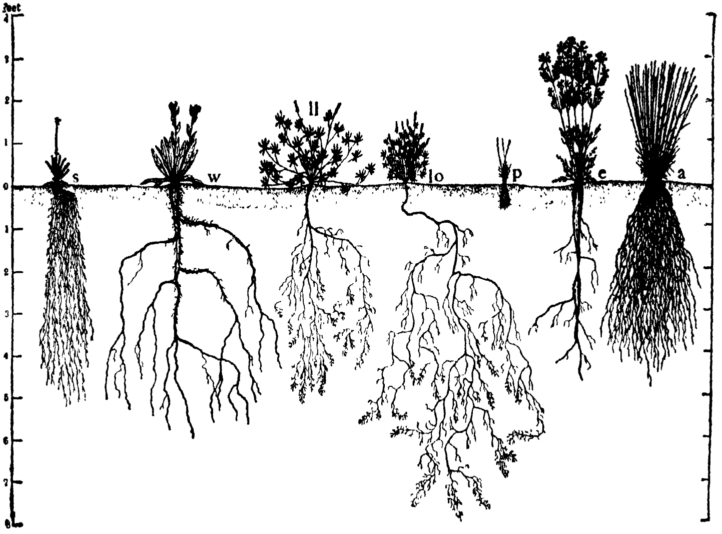

Fig. 7. Roots of prairie plants (U.S.A.) drawn to scale. *p.* and *a.*, grasses of different types; *ll.* and *lo.*, two species of lupin; *e.*, a member of the carrot family; *s.* and *w.*, other flowering plants. [From Weaver.]

the tree in the ground, enabling it to remain upright and more or less steady in the wildest storms. It must therefore be strong and extensive enough to hold in the soil and must extend in all directions. When we do see the roots of a tree it is usually when the anchor has proved inadequate and the tree has been blown down, but we notice even then that they are strong and woody and very like the branches of the tree.

Of course anchorage is not the only function of the root. We

know that plants need water and that this is taken in from the soil. We know, too, that the kind of soil is important—that there are poor and rich soils. From this it is easy to believe that roots take in something more than water. Actually it has been shown that they take in salts.

The *stem* is the above-ground, woody part ascending from the root and dividing above into *branches* and *twigs*. The lower part we call the *trunk* and one of its functions is to support the branches with their leaves, etc. It is clear, however, that the water taken in by the roots passes through the stem to the rest of the plant, for the leaves soon droop (or wilt) if the plant becomes short of water. So it appears that a second function of the stem is to conduct water (and, as we shall see, dissolved salts and food).

The tree lives for many years and is exposed to "all winds and weathers" and to danger of damage from cuts and blows, insect bites and so on. We are not surprised, therefore, to find that the surface is protected by a thick, waterproof *bark*. As the paint advertisements have it: "Save the surface and you save all."

Upon the twigs we find the *leaves*. Each has a short stalk and a thin, flat blade. The stalk is continued through the blade as the mid-rib and from this a number of branching "veins" extend. Stalk and veins are more resistant to decay than the rest of the leaf, and we often find them remaining as a "skeleton-leaf".

The leaves are spread out in such a way that each presents a large surface to the light and air and it has been shown that they actually make the food of the plant (sugars, etc.) from simple materials (carbon dioxide and water)—a thing no animal can do. So it happens that animals must obtain their food from green plants. It may strike you as odd that leaves are so all-important!

A great deal of energy is needed to bring about the formation of sugars and this is absorbed from sunlight by the green substance (*chlorophyll*) of the leaves. The carbon dioxide used is taken in from the air through tiny openings (*stomata*) in the leaves. The water, as we have seen, is brought up from the soil through roots, stem, leaf-stalk and veins.

The cherry-tree drops its leaves in the autumn—we say it is *deciduous*—but many trees keep their leaves through the winter and these we know as *evergreens*. The pine, yew and holly are familiar examples. Although the deciduous trees are bare in winter, we find that provision for making a fresh crop of leaves is already apparent in the form of *buds*.

Although most trees are flowering plants many of them have such tiny inconspicuous flowers that we are likely to overlook them. Few of us would notice those of an oak but a cherry orchard in spring-time is a sight never to be forgotten. The

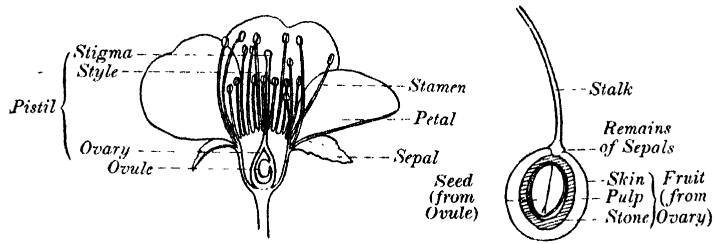

Fig. 8. Flower and fruit of cherry, shown in section.

most obvious parts of the *flower* are usually the petals, while around or below them are the sepals which protect the flower when it is a bud. Within we find the "essential organs" —the stamens, whose anthers produce the pollen, and the pistil, at the bottom of which is the ovary containing the ovules or young seeds. Provided that some of the pollen from the same flower or from another flower of the same species is brought to the top of the pistil, the ovule develops into a seed. This development continues after the flower has "died off" (see Fig. 9): actually the ovary does not die when the other parts do but grows and ripens till it becomes the *fruit* we know and like so well. In the case of the cherry the "kernel" within the stone is the seed and this, if planted in suitable soil, will germinate and grow up to form a new cherry tree.

THE GREEN PEA

If we plant the peas taken from a ripe pod (we like to eat the peas in the young, unripe state) they will grow into straggling plants. If given some support they will develop within a few weeks into plants several feet in height. Here there is no woody trunk but a thin, tender, herbaceous[1] stem bearing leaves, flowers and fruit. The leaves are rather different from

Fig. 9. Flowers and a young fruit of the pea. Note the withered stamens and the dying style. [Photo: R.D.G.]

those of the tree that we have described. Each is divided into leaflets and a branching tendril which twists around any support, enabling the plant to climb in spite of its weak stem.

The flowers are fairly large, white and almost unscented (in the Sweet Pea, which is cultivated for flowers rather than for peas, the flowers are much larger, brightly coloured and

[1] A herbaceous plant is one whose stems are not woody.

highly scented). If we open a flower we find within it the pollen-bearing stamens and a tiny green pod. This latter develops into the fruit—the pea-pod as sold in the shops. It contains the seeds—the peas which we eat.

ANIMALS

THE EARTHWORM

The earthworm may seem to be rather an unusual thing to take as a "typical" animal but we do so because it is simple enough for us to see the various parts easily and to understand the way in which they work together. It is rather a lowly animal but it is by no means unimportant, for its habit of eating out its own burrows means that it plays an essential part in powdering the soil and letting fresh air into it. Charles Darwin, whose name is usually associated only with the theory of Evolution, was mainly responsible for pointing this out. He calculated that in many parts of England the soil contained as many as 50,000 worms to the acre[1] and that each year more than ten tons of soil per acre passed through their bodies and was brought to the surface as casts. "The plough", Darwin wrote, "is one of the most ancient and valuable of man's inventions: but long before man existed the land was in fact regularly ploughed, and still continues to be ploughed, by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as these lowly organised creatures."

Most of an animal's time is spent in feeding or in seeking food (or in avoiding being eaten itself). Food is necessary for two things—for body building and for providing the animal with energy. Hence it is needed in every part of the body and since the only thing in the body which is capable of carrying it around is the blood, the food must pass into the blood. Practically all food when eaten is insoluble (as you know, you cannot dissolve bread, butter, meat, etc. in water) but when such food is made soluble (i.e. when it is *digested*) it can pass into the blood through the walls of the blood vessels and so

[1] A modern estimate is nearly a million to the acre!

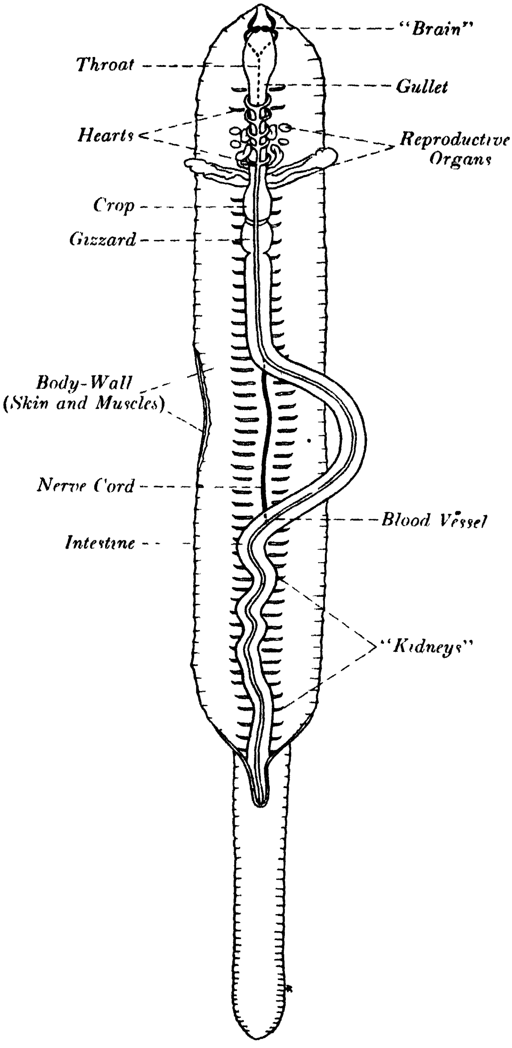

Fig. 10. Dissection of an earthworm: part of the intestine has been looped aside to show the nerve cord below it.

be carried around without fear of choking the vessels. Thus we shall expect to find some arrangement in the worm for digesting the food. This is the *food canal* or *gut*, an almost straight tube starting at the mouth, with a muscular throat used for sucking in the soil, which the worm swallows for the sake of the dead plant and animal remains (*humus*) on which it feeds. After a short *gullet* we find a thin-walled *crop* for storage, a muscular *gizzard* in which small stones are used to grind the material to a fine powder and then the long length of *intestine* in which the digestion takes place. A number of complex chemical substances known as *enzymes* are responsible for this. The digested food enters the blood vessels which surround the intestine while the indigestible remainder passes out of the worm at the *anus*, resulting in the worm casts we find on our lawns.

In addition to digested food, the *blood* carries oxygen to all parts of the body and collects waste material resulting from muscle action and other activities of the animal. The main blood vessels of the worm may be seen above and below the food canal, while the hearts that maintain the circulation of the blood (for in the worm these may be from six to fourteen in number) can be seen as semicircles around the gullet.

The *muscles* are the means by which the animal is enabled to move and in the worm they form a layer under the skin. They obtain their energy by what is really a slow burning of food by oxygen, waste products such as carbon dioxide and water being formed in the process. We may write a simple equation for this very important chemical change:

$$\text{Food} + \text{Oxygen} \rightarrow \text{Energy} + \text{Waste}.$$

We have seen already that the blood carries the oxygen and also the waste products. Now the blood flows in the blood vessels and the gases (oxygen and carbon dioxide) must pass through the walls of these. This is possible when the blood vessels are separated only by a thin, moist skin from the air. Only the smallest blood vessels have such thin skins. The skin of the body wall in the earthworm is very thin, is always kept moist by special glands, and is plentifully supplied with fine blood vessels. Thus the worm can breathe through its *skin*,

which is more than a mere protective layer since it serves as a lung as well.

Other waste matter collected by the blood is filtered out ("excreted" is the biological term) by the *kidneys*—or "nephridia" as they are called in the worm. Two of these occur in nearly every section (or *segment*) of its body.

The muscles in each segment are separate but it would be very awkward for the worm if they all acted independently of each other. Just imagine what would happen if one part of the worm tried to go forward while another part tried to go back! This sort of catastrophe is prevented by the *nervous system* which "co-ordinates" the working of all the parts, so that the worm acts as a single unit. Moreover, it is important that the animal should act in relation to what is going on around it—it would be useless for the animal to act as a whole if it were without senses by which to regulate its behaviour so as to take care of itself. The worm has neither sight nor hearing but it has an extremely delicate sense of touch due to nerve endings in the skin. It is said that it can even feel the shaking of the soil caused by a person walking across the lawn towards it when the person is still some distance away. The main nerve cord of a worm can be seen as a white thread under the food canal. With a lens some of the connections to the muscles and to the skin of the front (anterior) end of the animal may be seen. There is a nerve centre in each segment of the body and a main nerve centre (scarcely big enough to be dignified by the term "brain") is just above the mouth.

One other thing that we shall expect to find is some arrangement for making the eggs from which new generations are formed. Such *reproductive organs* are found in the front part of the worm.

THE COCKROACH

Since insects are the largest group of living things (over half a million different species are known and that is probably only a fraction of the total) we ought perhaps to be familiar with the structure of at least one typical example. The cockroach is the type usually chosen for study since it is comparatively large.

The animal is composed of segments and is divided into three parts—head, thorax and abdomen. The whole body is covered with a hard layer of "chitin", which acts as an *external skeleton* (p. 37); this is quite thick on the head but thin enough at the joints to be quite flexible.

The head bears the feelers or *antennae*, the eyes and the jaws. The feelers are jointed and taper gradually to the tip: they bear sense organs of touch and of smell and are continually moving. The eyes are built on a totally different plan from those of a mammal (p. 214). They are composed of several hundreds of small six-sided tubes, almost but not quite parallel to one another. Each tube appears to contain only a single nerve ending and merely to register, as a light or dark

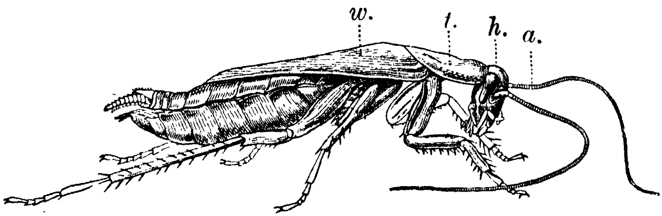

Fig. 11. Cockroach (× 2). *a.*, antenna; *h.*, head (note eyes and jaws); *t.*, prothorax; *w.*, wing-cases.
[From Shipley and McBride]

spot, what is directly in front of it: the picture so formed must be of the nature of a very coarse-grained newspaper photograph. The jaws or *mouth parts* too are peculiar in that they are outside the mouth, left and right instead of top and bottom, and consist of three overlapping pairs. The chief of these are the two *mandibles* with strong toothed edges. The others are the *maxillae* and the *labium*: these not only help in mastication but, on their feelers or *palps*, bear sense organs of touch, and probably also of taste.

The thorax is composed of three segments—the *pro-*, *meso-* and *meta-thorax*. Each of these bears a pair of many-jointed legs, the feet of which end in tiny claws. The top of the prothorax is so large that it overlaps part of the head and of the mesothorax. The mesothorax bears a pair of hard, almost

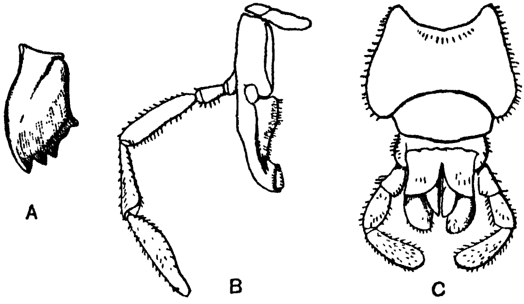

Fig. 12. Mouth parts of cockroach. A, left mandible; B, left maxilla; C, labium. (The last is really a pair of jaws, the bases of which are joined together forming the floor of the mouth.)

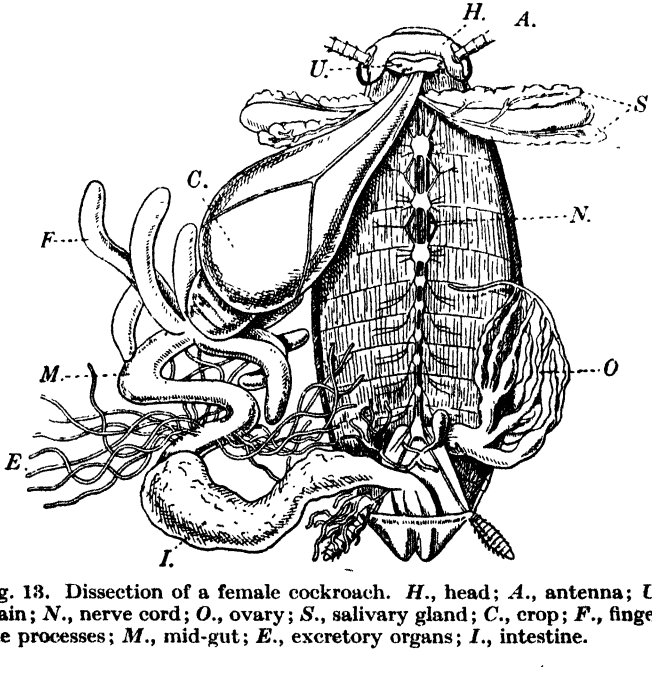

Fig. 13. Dissection of a female cockroach. *H.*, head; *A.*, antenna; *U.*, brain; *N.*, nerve cord; *O.*, ovary; *S.*, salivary gland; *C.*, crop; *F.*, finger-like processes; *M.*, mid-gut; *E.*, excretory organs; *I.*, intestine.

oblong, wing cases while the metathorax bears the large, delicate wings which are used for flying and are folded up under the wing cases when not in use.

The *abdomen* consists of ten segments, of which the eighth and ninth are very small.

The arrangement of the internal organs is fairly simple. The food canal begins with a large crop in which most of the digestion takes place. (The starch is digested by enzymes[1] in the saliva, while the finger-like processes which open into the mid-gut make enzymes for the digestion of the proteins[1] and fats.) The digested food passes into the blood in the region of the *mid-gut* and the intestine not only conveys undigested food to the anus but carries away waste matter filtered from the blood by the thread-like excretory organs. The blood wanders freely throughout the body-space —there are practically no blood vessels—being kept on the move by a long tubular heart which lies above the food canal. Below the food canal lie the reproductive organs and the nerve cord. The latter is double and has a pair of nerve centres in practically every segment: the centres in the head are the largest.

Insects have their own way of breathing. The oxygen is not dissolved in, and carried round by, the blood as in most other animals but has direct access to every part of the body through a system of finely-branching air tubes or *tracheae* (p. 157). The air enters these through a series of *spiracles* openings along the side of the body rather like a row of port-holes along the side of a ship (Fig. 100).

Eggs are laid in batches of sixteen and the young *nymphs* (p. 249) which hatch from them pass through a series of seven moults (p. 242) and grow up to adults in about twelve months.

Mammals

In this book we shall be dealing, as far as animals are concerned, mainly with man and other *mammals*—these being defined roughly as animals with backbones and with hair on the skin. They have more or less the same sets of organs as an earthworm but the arrangement is different. Among the most

[1] See chap. VI.

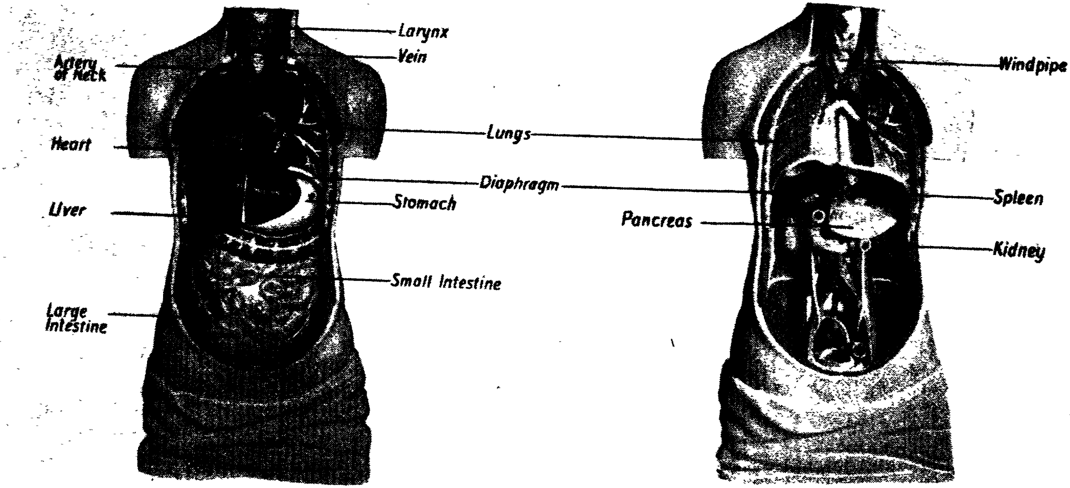

Fig. 14. Models of the human body, showing the arrangement of the main organs. [Courtesy of Messrs W. and J. George and Becker Ltd.]

obvious differences are the possession of a skeleton and of a definite head containing the brain and such sense-organs as eyes, ears and nose. Another difference is that mammals have four limbs —arrangements of bone and muscle—by which the animal moves. The main part of the body is hollow as in the worm but the body-space or *coelom* is divided by the diaphragm into two parts, thorax and abdomen. Within the thorax are the heart and lungs while the abdomen contains

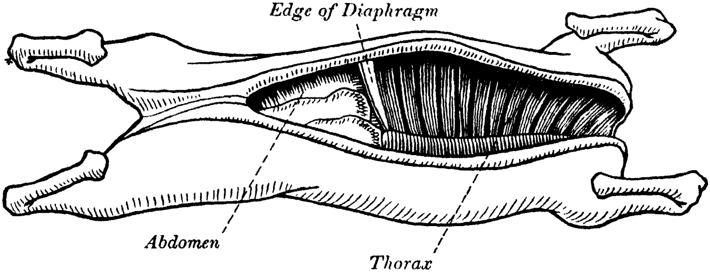

Fig. 15. Carcase of a sheep, to show the divisions of the body-space.

liver, stomach and intestines, kidneys and reproductive organs. The walls of the coelom are composed of sheets of muscle under the skin and these muscles are especially thick around the backbone and ribs.

PRACTICAL WORK

Much of the text of this book is arranged on the assumption that you will do at least the more important parts of the practical work for yourselves. For this reason details which you should observe are not usually discussed or illustrated in the text.

It is very important that you should examine actual specimens while you are reading the various chapters and make careful drawings from them (and not from drawings in this, or any other, book). Use a lens for small parts.

1. Learn how to recognise the different types of plants and animals (e.g. algae, mosses, insects, reptiles) which you find in your gardens, on country walks, in ponds and at the seaside, in parks and zoological gardens, etc. There should be various books in your school and local libraries which will help you in this.

2. Examine various plants and flowers and identify their "parts".

3. Watch the growth and development of seeds planted in your garden or in connection with the practical work of Chapter xv.

4. Watch the opening of flower buds (the Evening Primrose is particularly rapid) and other buds, and notice what happens when flowers "die off".

5. Dissect an earthworm (drowned in methylated spirits and then washed in water). Cut it along the back with fine scissors and then cut through the *septa* (cross-walls). Pin the body wall down. The dissection can be done in a shallow dish of water, the bottom of the dish being covered with a mixture of beeswax, paraffin wax, and lampblack.

6. Observe the behaviour of a living cockroach when walking, feeding, etc., and make your own drawings of its external features.

7. Observe the use of antennae by a millipede.

8. Observe the action of the external jaws in a living caterpillar, crab or lobster.

9. Remove the contents of the head of a dead cockroach by boiling it in caustic potash solution, and after washing it in cold water, dissect off the mouth parts.

10. Dissect a cockroach killed by immersion in hot water. Remove the wing cases, wings and plates of chitin covering the back. The organs will be found embedded in fat.

11. Look at the carcase of a sheep or pig hanging in a butcher's shop and notice the coelom. Notice, too, the position of the ribs, diaphragm and kidneys.

12. Observe the position of the organs when cleaning a rabbit, chicken or fish.

13. Examine any dissections available in a museum.

14. Carry out the dissection of a rabbit. For detailed instructions see Hill, *Manual of Human Physiology*, pp. 58–63, and other zoolog xt-books.

CHAPTER II

PROTOPLASM

Not every part of every living thing is alive. In our own bodies, for example, the finger-nails and hairs are themselves dead though they grow from living roots. Again, what we

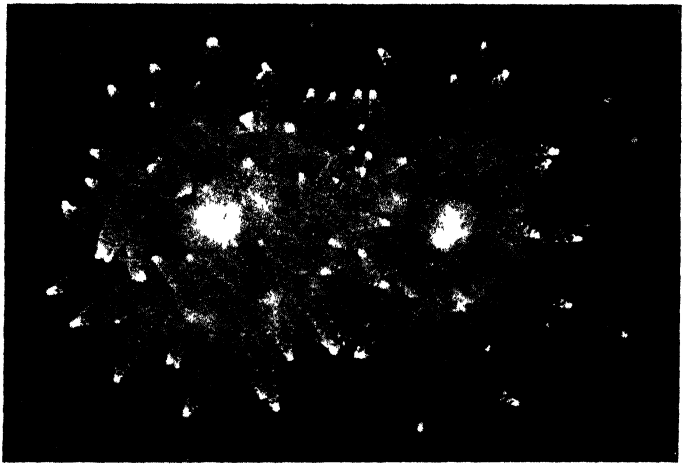

Fig. 16. Two living polyps of the Golden Star Coral—a rare British species. Most corals are composed of thousands of polyps linked together by strands of protoplasm, but in this species each polyp is a separate organism. [Photo: D. P. Wilson.]

usually call "coral" is merely the dead skeleton formed by the thousands of polyps of the living organism.

In plants a very large proportion of the body may be of non-living material. Thus in a large tree the dead heartwood may be very extensive and in some cases it may decay and

disappear leaving the tree hollow—but the rest of the tree can continue to live for many years.

The actual living material in all living things is known as *protoplasm*. It is an almost transparent, slimy, semi-fluid substance, not unlike uncooked white of egg. It is difficult to describe its exact physical state, for it is able to flow like a liquid and yet it is elastic.

In living things which are large enough to be seen by the unaided eye the protoplasm is not usually obvious because of the presence of a dead outer skin and other (dead) substances. There are some small organisms, however, which are composed of pure protoplasm, and since with the aid of a microscope it is comparatively easy to study them we may well start a chapter on protoplasm by considering one of the best known.

Amoeba

Amoeba is a microscopic animal, usually about half a millimetre across, which lives at the bottom of muddy ponds. It

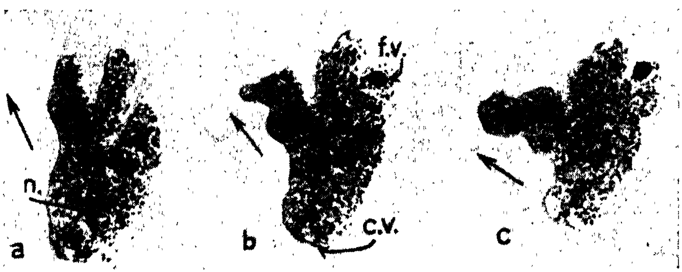

Fig. 17. Amoeba. Three photographs of the same individual, taken at intervals of approximately 20 seconds. Arrows show the direction of motion. *n.*, nucleus; *f.v.*, food vacuole; *c.v.*, contractile vacuole. (× 50.)
[Photo: Prof. F. E. Lloyd.]

is a tiny speck of naked protoplasm, but it is evident on examination that there is a definite boundary between the protoplasm and the surrounding water. It is possible to prove this by using a needle of microscopic fineness to scratch the

surface of the animal. If only a tiny tear is made the protoplasm oozes out but does not mix with the water—it forms a new boundary and the Amoeba continues to live. If a large tear is made the protoplasm flows out so quickly that no emergency "skin" is made and then the protoplasm mixes with the water and the animal dies. It seems quite certain, in fact, that there is always a definite boundary—like a very thin skin—on the surface of protoplasm.

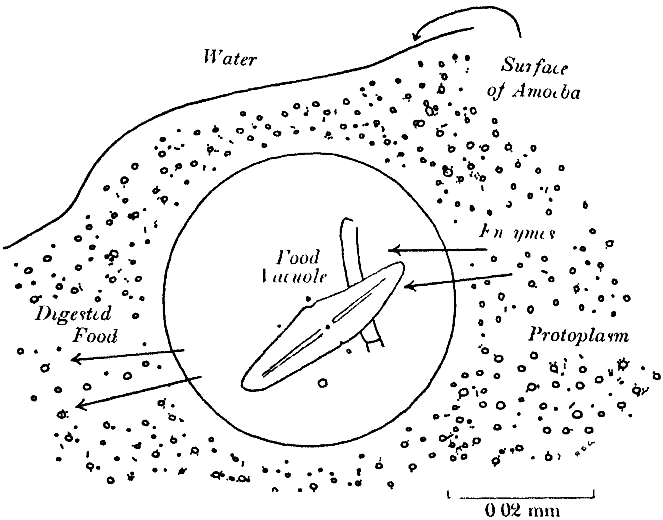

Fig 18 A small part of an Amoeba, greatly magnified, to show a "food vacuole".

If we continue our study of Amoeba we find that a more or less spherical part of the inner protoplasm is somewhat different from the rest. We call this the *nucleus*. It is a very important structure and there is reason to believe that it controls the activity of the rest of the protoplasm.[1] Part of the evidence for this is worth considering here. It is possible, though far from easy, to operate on an Amoeba and to divide

[1] The term *cytoplasm* is often used for this protoplasm as distinct from the nucleus.


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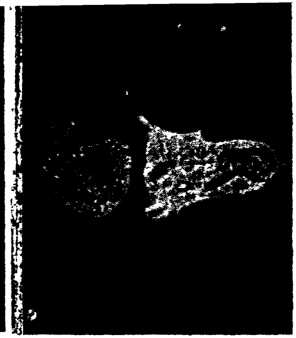
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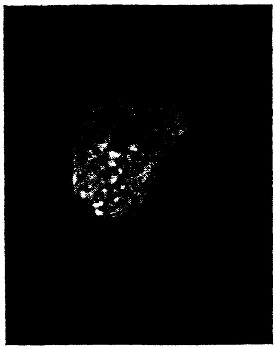
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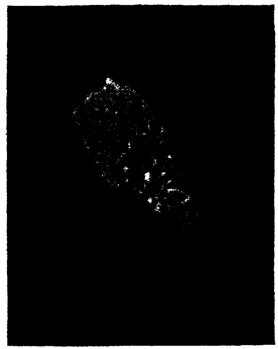
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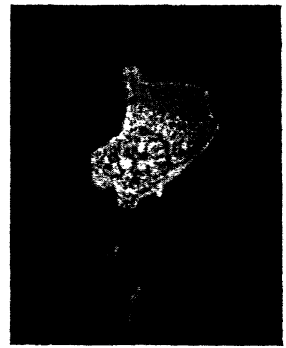
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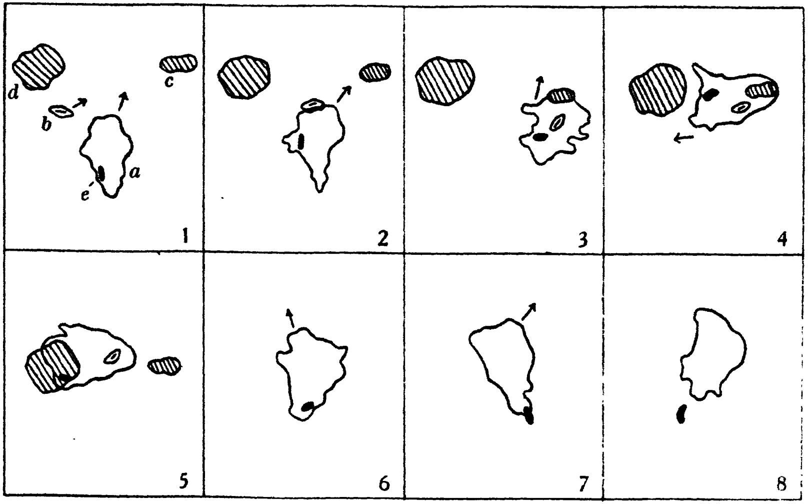


Fig. 19. The feeding of an Amoeba: a set of photographs from a cinema film taken by Prof. F. E. Lloyd: the background of these photographs has been retouched. Fig. 20. Diagrams based on the photographs. 1, An Amoeba (*a*) and a diatom (*b*), both moving; *c* and *d*, pieces of inedible debris; *e*, another diatom within the Amoeba. 2, Four seconds later: the Amoeba and diatom have met. 3, After a further 20 sec. The Amoeba has swallowed the diatom and is swallowing *c*. 4, About one minute later: *b* and *c* can be clearly seen inside the Amoeba. 5, About 50 sec. later: the Amoeba has ejected and moved away from *c* and is trying (unsuccessfully) to surround *d*. 6–8, The shell of the diatom (*e*) is being ejected. (7 taken 40 seconds after 6, and 8 about 20 seconds after 7.)

it into two parts—one part with and one without the nucleus. It is found that in such cases the part containing the nucleus continues to live and grow; while the other part may live for a time but does not grow and eventually dies. We shall see, later, that every unit of protoplasm has its nucleus.

Amoeba is able to move about and if we study it under the microscope we find that this movement is due to flowing of the protoplasm in one direction or another. Curious changes of shape result from this flowing and as a matter of fact the very name Amoeba means "change".

This flowing movement may bring the animal near a suitable piece of food and when this happens we find that the protoplasm simply flows around and engulfs the food. Before the solid food can be used by the protoplasm it must be digested and we notice that this goes on in a little drop of liquid (a *vacuole*). Amoeba often feeds upon diatoms. These are tiny plants which have an indigestible covering of silica. In this case, the inside of the plant is digested (the silica covering is porous) and the indigestible covering is left behind when the animal moves on.

If the animal is able to get sufficient food, it grows. It seems that there is a limit to the size which a single Amoeba may reach. When that limit is attained the organism divides in two. This is a very simple and straightforward method of reproduction. We referred above to an experiment in which a single Amoeba might be cut into two. In that case the piece without the nucleus dies. Here, however, the nucleus divides first and so each new Amoeba has its nucleus and each is actually a complete new individual.

Further study of this interesting little animal shows the presence of another and very fascinating structure. This is a little bubble of liquid which appears in the protoplasm, grows larger and larger and then suddenly bursts to the outside of the Amoeba. This is known as the *contractile vacuole*. It gets rid of excess water taken in by osmosis (p. 33). It is almost certain, too, that various waste products also are excreted in this way.

We have seen that Amoeba moves actively about in search of food and this requires energy, as do its other activities (such as growth and reproduction). The obtaining of this

energy from food by respiration involves the taking in of oxygen and the release of carbon dioxide as a waste product. Both of these gases are soluble in water and the boundary of the protoplasm is such that they diffuse (or soak) through it quite easily.

Spirogyra

While Amoeba is a very good type of small, simple animal a brief description of a simple water plant may help us to understand later chapters. There are many of these plants, differing from each other in detail, but very much alike

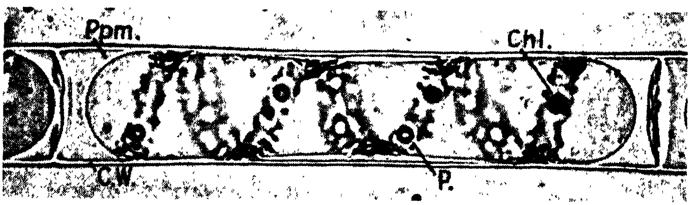


Fig. 21. A single cell of Spirogyra, "plasmolysed" (p. 34) so that the protoplasm is visible. *Ppm.*, protoplasm; *Chl.*, chloroplast; *C.W.*, cell-wall; *P.*, pyrenoid. The nucleus is not visible. (× 300.)
[Photo: Prof. F. E. Lloyd.]

in principle. The type that we have chosen—*Spirogyra*—can be distinguished from most of these by its slippery feel.

A handful of Spirogyra consists of a tangle of long, green, unbranched threads (sometimes called "Water-silk" or "Mermaids' Tresses") which have a very definite form and structure - quite unlike the shapeless mass of Amoeba. Under the microscope we see why this is so—each thread has an outer *cell wall* running its whole length. This cell wall is composed of cellulose (the same substance as that of which cotton-wool is composed) and covered with mucilage, a gummy substance which makes it feel slimy. If we look closely we see that there are cross-walls which divide the thread into units. Each division contains protoplasm and a nucleus and is usually called a *cell* (p. 28).

All the cells of Spirogyra are exactly alike—each being about one-fifth of a millimetre in length—and are practically independent of each other. (In fact, under some abnormal conditions the thread may break up into single cells which can live for a long time and which may even grow and divide to form whole new threads.)

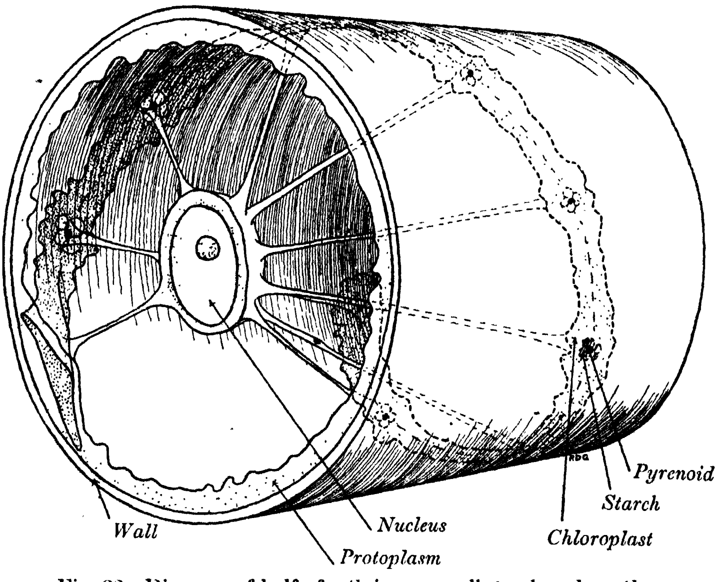


Fig. 22. Diagram of half of a Spirogyra cell, to show how the nucleus is suspended by threads of protoplasm.

When we examine a single cell we find that the most obvious thing is the coiled *chloroplast* which contains a green substance, chlorophyll, and is the actual seat of the manufacture of sugar. The little bodies in the chloroplast are *pyrenoids* which appear to be the centres at which the sugar is changed to starch for storage. The nucleus and some of the threads of protoplasm radiating from it can be seen by careful focusing under the high power of the microscope, but the main mass of the protoplasm is very difficult to see under normal

conditions, as it forms a thin layer closely pressed to the cell wall. The central part of the cell contains "sap" and is known as the *vacuole*.

The cells grow until they reach a maximum length (which varies with the more than two hundred kinds of Spirogyra) and then each divides to form two cells. The nucleus divides first, then a new wall grows across the cell, gradually pinching the protoplasm into two and making the separation complete. New threads are formed either by the old threads breaking into small pieces (each piece then growing independently), or from special *zygotes*. These are formed when, in two filaments

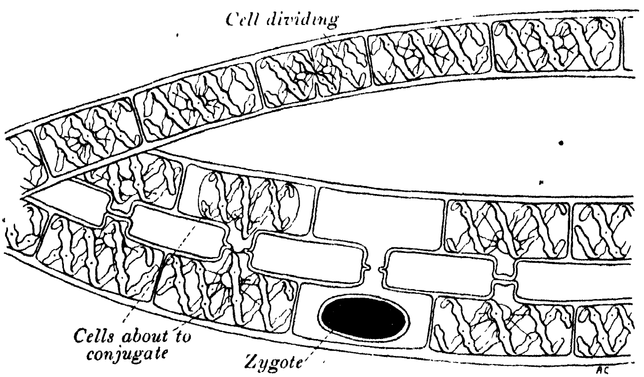


Fig. 23. Filaments of Spirogyra, as seen under the microscope: in each cell, the nucleus and protoplasm are shown. The middle cell in the upper filament is dividing while those in the lower pair of filaments are in various stages of conjugation.

lying side by side, cells opposite one another grow projections which unite to form tubes. Through each tube one cell of the pair passes and joins completely with the other cell, a process which is called *conjugation* (p. 225). The sap is expelled by temporary contractile vacuoles; and the zygote which results forms a thick wall around itself and is capable of resting for long periods.

Protoplasm in Larger Organisms

Few living things are as simple as the two which we have so far been discussing in this chapter. One of the main differences is that, whereas Amoeba consists of a single unit or cell, larger organisms have their protoplasm divided into few or many cells. Thus we say that whereas Amoeba is *unicellular* larger organisms are *multicellular*.

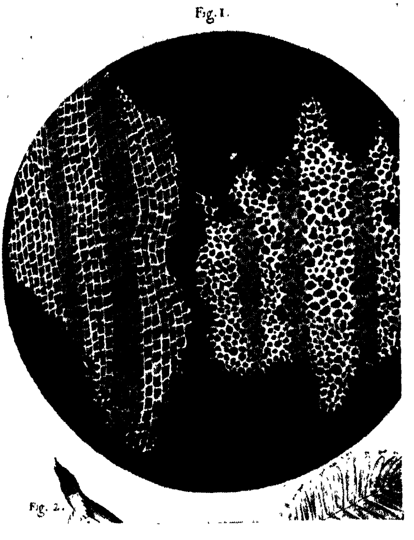


Fig. 24. Two of Hooke's original drawings of cork, from his book *Micrographia*. [Photo: R. D. G.]

If we mount scrapings from the inside of the human cheek in water and examine them under the microscope, we shall see some of the cells from our own body. A single leaf of a moss plant, the skin of an onion scale, and a thin section of almost any part of a plant or an animal will show us numbers of cells.

The name "cell" is actually very unsuitable. It was suggested about 1660 by Hooke, who examined a very thin slice of cork with one of the first microscopes. He saw a series of

little box-like compartments and naturally called them "cells". It is very unfortunate that cork was the material used, for it is a dead material: the living protoplasm by which the little "boxes" are formed dies as soon as it has finished the work of building what is really only a cell wall. We have seen such cell walls in the case of Spirogyra cells and they are normally present in all plant cells. In most animal cells,

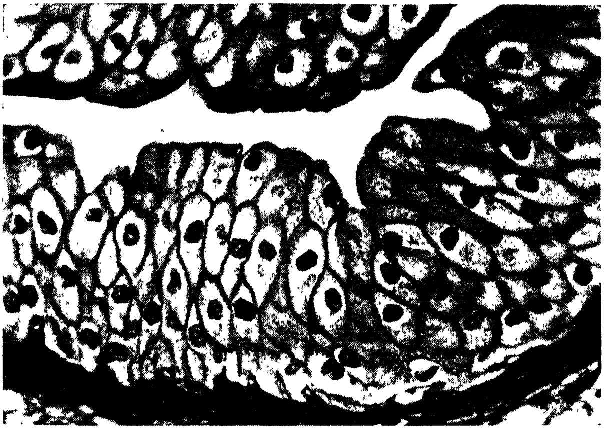


Fig. 25. Cells in the lining of the bladder of a rabbit. The lines between the cells are merely the cell boundaries. They are not cell-walls such as are found in plants. (× 300.)
[Photo: P. G. 'Espinasse.]

however, they are not present and this helps to point out the fact that *it is the living protoplasm and not the dead cell walls which is of primary importance in Biology.*

When we use the term "cell", therefore, we must think of a unit of living protoplasm with its own nucleus. We must realise that every living part of every living thing is composed of these living cells. A leaf is made up of hundreds of thousands of cells: the kidney, the heart, the brain and all the other organs of the animal body are composed of millions of cells.

In the various organs the cells obviously have different

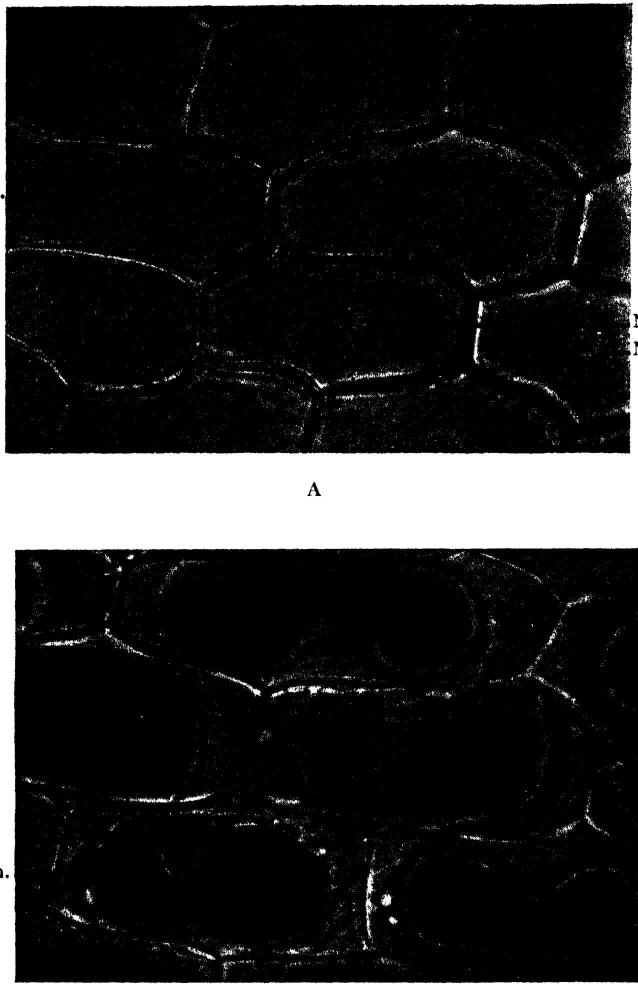


Fig. 26. Cells from the inner skin of an onion scale. A, in their natural state. B, plasmolysed. C.W., cell-wall; N.N., nuclei; Ppm., protoplasm. [Photos: J. H. Whyte.]

functions to perform and just as we have various types of motor-cars, each *specialised* for its own particular function—, e.g. for touring, for racing or for carrying heavy loads—so the cells in multicellular living things are usually specialised. For example, the protoplasm of Amoeba is capable, among other things, of movement and of conducting stimuli (p. 189). In larger animals, we find certain "muscle" cells specialised for movement and other "nerve" cells with extremely long thin strands of protoplasm specialised for conducting stimuli (Fig. 125). Again, in multicellular plants some cells carry on photosynthesis (Fig. 55) while others are specialised for strengthening the plant or for the transport of food and water (Fig. 55). Thus a living thing may contain quite a large number of different types of highly specialised cells and so we speak also of the *differentiation of cells* (p. 246).

Tissue Culture

We have stressed the fact that the parts of a plant or animal—and even the individual cells—are *alive*. That this is true can be shown by the fact that such parts (or even a few cells) can be kept alive even after the death of the plant or animal of which they formed a part.

Protoplasm has certain definite needs (see Chapter VIII) and if these are met its life continues. Thus, if by artificial means we can satisfy those needs, we can keep it alive for long periods. During the last few years many attempts have been made to do just this, and some of these experiments have been very successful.

We all know that cut flowers or twigs bearing leaves can be kept alive if given water, and isolated organs from an animal's body can be dealt with in much the same way. The isolated heart of a frog or rabbit can be made to work for hours if supplied with a blood substitute which gives it the necessary food and oxygen and keeps it moist.

An extremely interesting type of experiment is that known as *tissue culture*. Here small pieces of living tissue from, say, the heart of a chicken are kept under artificial conditions as closely similar to those of the body as possible. To achieve

this they are placed in a tiny glass chamber which is very similar to that shown in Fig. 143, the main difference being that a watertight ring of wax is used in place of the water. In this, the tissues are bathed by the blood-serum (the clear liquid left after blood has clotted) of the same species. Also, in the case of a warm-blooded animal, they are kept at the tem-

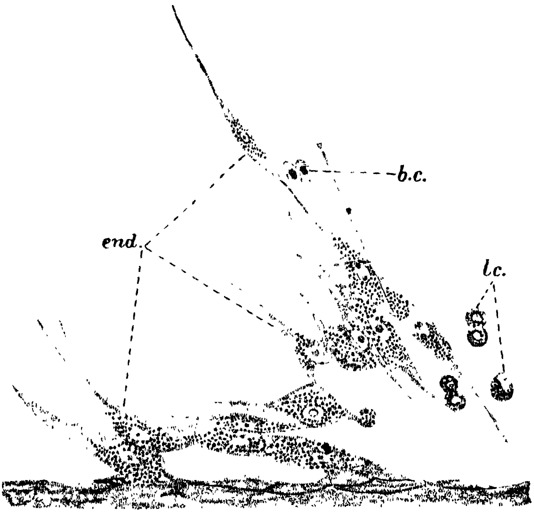


Fig. 27. A small portion of a tissue culture, started from a piece of a frog's artery. *b.c.* and *l.c.*, blood corpuscles—red and white respectively. *end.* cells multiplying from the lining of the artery. Notice the nuclei and protoplasm. [From *Cytology* by J. Gray. After Drew.]

perature they would have enjoyed in the animal's body. Under such conditions, the isolated cells settle down and not merely go on living but grow and divide.

The most famous of these experiments is one started in New York about 1913 and using the cells of a chicken—the culture is still (1946) living and appears to be as vigorous as ever. Even the toughest of hens does not live as long as this and it would appear that under such conditions the protoplasm attains immortality! Tissue culture with plant cells is

not so easy, but, even so, some successful experiments have been reported.

If we attempt to grow different kinds of cells from the same organism we find that they require somewhat different treatments. This cannot but impress us with the complexity of the single organism in which all sorts of different cells with their differing needs work together for the common good. In recent years it has been found that much of the necessary co-ordination is due to chemical substances present in small quantities in the blood and called *hormones*. We shall have more to say of these later (p. 202).

OSMOSIS

If we separate two solutions of different strengths, or a solution and water, by a membrane such as cellophane we find that the membrane is *semi-permeable*—the water will pass through the membrane but the dissolved substances will not do so or will do so only very slowly. In such circumstances, water tends to pass through the membrane in the direction of the stronger solution. This phenomenon is known as *osmosis*.

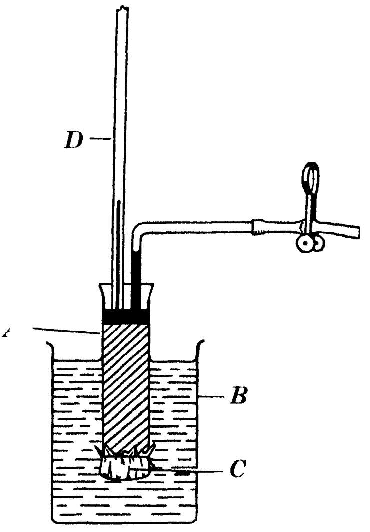


Fig. 28. Experiment on Osmosis.

Fig. 28 shows an apparatus by which this can be demonstrated. The tube *A* contains golden syrup which is, of course, a very strong sugar solution. Ink is floated on the syrup and the side tube used to adjust its level in the capillary tube *D*. The syrup is separated from the water (or weak sugar solution) in the beaker *B* by the cellophane membrane *C*. Water passes in through the mem-

brane (i.e. from the water to the syrup) and the consequent expansion of the syrup causes the ink to rise quite rapidly in the capillary tube. If the syrup and water were reversed the level of liquid in *D* would, of course, fall.

Any surface of protoplasm such as the outer surface of Amoeba can act as a semi-permeable membrane and so osmosis is a very important phenomenon in living things. For example, Amoeba lives in almost pure water while its protoplasm, like any other protoplasm, contains all sorts of things in solution. Hence the water of the pond continually passes into the protoplasm of the Amoeba (just as it passed from the weak to the strong solution of sugar in the experiment described above). We have seen that Amoeba gets rid of this water by means of its contractile vacuole.

In a plant cell such as Spirogyra we do not normally find contractile vacuoles. Water is taken in by the protoplasm, just as in Amoeba, and it collects as the central vacuole (which contains much dissolved material). This distends the protoplasm and forces it against the wall. As more water passes in, the wall is actually stretched until it resists so strongly that no more water can enter. The cell is then very like an inflated motor-car tyre, held rigid by this "osmotic pressure". We say that it is *turgid*. (The osmotic pressure within the cell is often very high: in Spirogyra, for example, it may be as much as 150 lb. per square inch.)

We can experiment with Spirogyra and other plant cells and see that their turgid condition depends upon the intake of water by osmosis. If we mount filaments of Spirogyra in water and in various strengths of sugar solution we can see by actual measurement that the wall is fully stretched in water and less strongly so in dilute sugar solution. In strong solutions so much water is withdrawn from the cells (compare the movement of water through the semi-permeable membrane in the experiment) that the protoplasm shrinks away from the wall and the cells are said to be *plasmolysed* (Figs. 21 and 26).

PRACTICAL WORK

1. Observe a living Amoeba under the microscope. (If you are to have an adequate idea of what protoplasm is, it is essential that you should watch an actively moving Amoeba for at least two or three minutes.) Amoeba is not easy to culture. Use shallow glass (e.g. "tongue") dishes containing about ¼ in. depth of pure soft water (e.g. distilled water). Once a week aerate the water with a fountain-pen filler and add two boiled wheat grains (removing old grains). Sub-culture every two or three months, cleaning the dishes thoroughly.

2. Movement of protoplasm can be seen in the cells of *Elodea* (p. 86) under the high power of the microscope.

3. Examine Spirogyra under the microscope. The protoplasm may be seen better by plasmolysing the cells, using 10 per cent. sugar solution.

4. Examine the cells in a moss leaf, in the thin skin of a laurel leaf or of an onion scale and in the scrapings from the roof of the mouth (taken with a spoon—or a thoroughly clean scalpel—which has been in boiling water for a few minutes).

5. Cut very thin sections of cork and compare them with Hooke's diagrams.

6. Macerate small pieces of the stem or other part of a plant. Cut the material into pieces about 5 mm. long and, if thick, slice lengthwise. Just cover in small dishes with a few drops of Jeffrey's macerating fluid (made by mixing equal parts of 10 per cent. chromic and 10 per cent. nitric acids. Be very careful not to get this on hands or clothes!). Set aside for a day or two and then add a large volume of water to the material. The treated stem may come apart of itself or it may be gently "teased" out with a fine needle. Mount in water and examine both with the unaided eye and with the microscope. Note especially the cells with woody walls.

7. Carry out the experiment on Osmosis, shown in Fig. 28. The membrane, of very thin cellophane, is tied on dry, with thin dry thread—and then wetted.

8. Leave grapes, prunes or currants, etc., in (*a*) pure water, (*b*) strong sugar or salt solution.

9. Fill a test-tube with salt or sugar solution (treacle can be used again) and tie a cellophane membrane over the mouth. Place the test-tube in water and notice how the membrane gradually becomes turgid.

CHAPTER III

SKELETONS

The Skeleton and Body Shape

Since the protoplasm of which all living things are composed is very soft and almost fluid, the larger living things, at least, need some more solid structure (i.e. a *skeleton*) to enable them to keep their proper shape. A few, like the jelly fish, that live in water depend on the buoyancy of the water to take their weight and so may dispense with a skeleton. Others such as Spirogyra, the earthworm, and parts of plants such as young leaves maintain their rigidity by being turgid (p. 34).

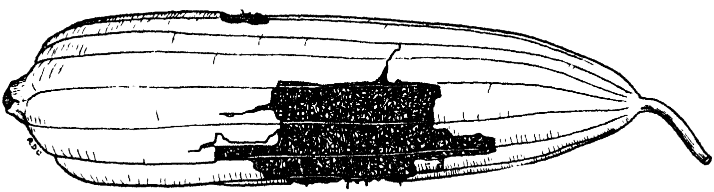


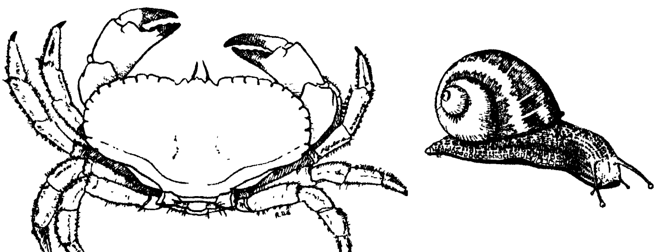
Fig. 29. A "Loofah" or "Vegetable Sponge"—really the vein skeleton of a fruit of the marrow type. The specimen here drawn had not completely rotted, a large part of its outer skin still remaining.

A skeleton, however, is absolutely necessary in practically all living things. You can imagine what would happen if some "invisible ray" were able to dissolve away the bones of an elephant or a human being or even a frog: such an animal without the support of its skeleton would become a shapeless mass of soft flesh and would "flop" like a poached egg! The larger plants must have skeletons for the same reason. The veins in a leaf carry water and food but are also important for preserving the shape of the blade. If you find a dead leaf with only the veins left, you call it a skeleton leaf—and quite rightly.

Some animals have *external skeletons* outside everything else —crabs and beetles, snails and oysters are obvious examples —whereas many others, including ourselves, have an *internal skeleton* composed of bones surrounded by the flesh. In addition to these skeletons there is a complicated arrangement of skins which keeps the various organs of the body in place (Figs. 62 and 65). Such skins are called *connective tissues* and are easily seen as semi-transparent skins in an uncooked joint of veal. Every part of the body is kept in place (and to some extent in shape) by such connective tissues, and if it were possible to dissolve away everything else in the body we could still trace the outlines of every organ—heart, stomach, lungs, liver and so on, and even the veins and nerves—preserved for us in the all-pervading scaffolding of connective tissue.

Skeletons as Protection

A skeleton may not only keep the living thing in shape but in animals may also protect either the whole body or the more important parts. In such animals as snails, crabs and beetles,



A B

Fig. 30. Animals with external skeletons. A, Crab. B, Snail.

the softer parts of the body are obviously almost completely protected from injury by the hard skeleton around them, but in backboned animals (*Vertebrates*) the protection is much less general. Even here, however, the more important and delicate parts are enclosed within bones. The brain and inner ear are surrounded by the bones of the skull and the eyes are deeply sunk in bony sockets. The spinal cord, which is the

most important set of nerves in the body, runs through a row of hollow spaces in the vertebrae of the backbone, while the ribs and breastbone form a complete cage round those very important organs, the heart and lungs.

The part of the human body which is most conspicuously exposed to possible injury is the abdomen—and, judging from the way in which through lack of exercise it develops a "bow-window" appearance in some people, you will realise that it has no part of the skeleton to preserve its shape or protect it!

Skeletons and Movement

Such animals as snails and mussels are completely protected when they withdraw into their shells but they do not enjoy the advantage, conferred by the possession of a *jointed skeleton* like that of crabs, beetles and the vertebrates. In animals with jointed skeletons the muscles are able to act on the jointed parts, moving them—rather like stilts—in such a way that the whole body is moved. The bones of the leg are good examples of this. It is true that it is the muscles that cause the movement but muscles alone would be useless to us without the solid bones which act as levers for them.

PLANT SKELETONS

We must now say a little more about the way in which the parts of plants maintain their shape. In the last chapter we saw that Spirogyra, a very simple plant, is composed of a single row of cells, each contained in its own cell wall, and such things as a moss leaf are composed of a comparatively large number of cells, very similar in structure to those of Spirogyra. In both cases turgidity is sufficient to maintain the shape. This is possible in the case of Spirogyra because the plant grows in water (or really in a very dilute salt solution) and has a much more concentrated cell sap. In the case of the moss the salt solution, taken in from the soil by the little rootlets of the moss, passes up through the stem and is in contact with the leaf cells which have a more concentrated sap. In both cases water passes by osmosis into the cells and keeps them turgid (p. 34). Young leaves and many young stems also owe their rigidity to this and not to any skeleton. This is clearly

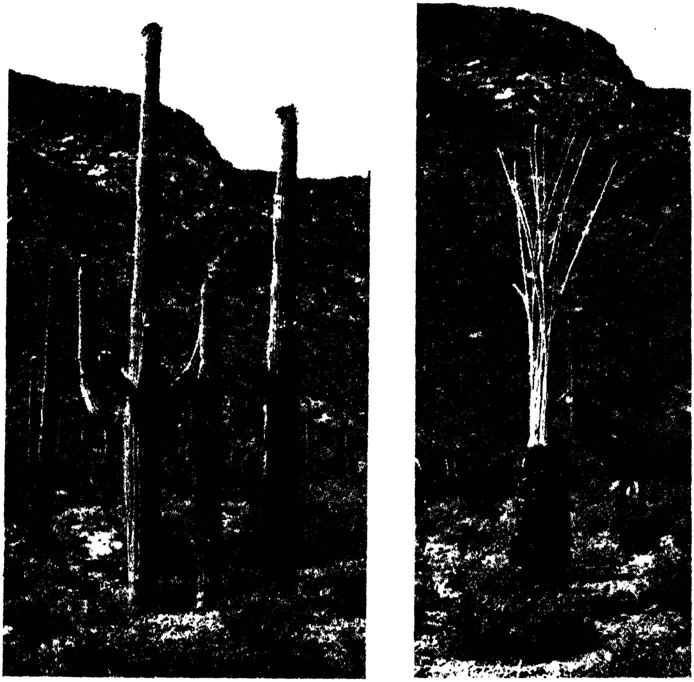
seen when the cells lose their turgidity—as they do when water evaporates from the plant more rapidly than it can be taken up (e.g. newly transplanted seedlings which are exposed to bright sunshine before their roots have recovered sufficiently from damage incidental to transplanting). In such cases the cells become flaccid and the leaves *wilt*. Similarly a cucumber or a lettuce owes its rigidity chiefly to the turgor of its cells and will gradually lose that rigidity if cut or pulled and left exposed to the air for a few days. The good housewife knows that a limp lettuce or soft cucumber is stale.

As we have already pointed out most parts of larger plants owe their rigidity not to turgor but to definite skeletons within them. This is very well shown in the giant cactus of the deserts of Arizona. The greater part of the huge stem (which may reach a height of seventy feet and weigh several tons) consists of water-storing cells. Although these are usually turgid, they alone could never support so great a weight as this and we find that the whole structure is reinforced by long, woody veins. These—like the bones of an animal—may persist after the fleshy part decays.

The cells which make up these "bones" are very different from those we have been considering in the last few paragraphs. Those had thin cell walls of cellulose but these have their walls very considerably thickened and strengthened by a harder and stronger compound known as ligno-cellulose, or more commonly as *wood*. Some of these cells have their walls thickened by rings, spirals or networks of thickening (Fig. 86 A) while others, called *fibres*, are very long, slender, cigar-shaped cells. All lose their living content of protoplasm when they are fully grown and since turgidity cannot be maintained in the absence of protoplasm they have to rely entirely on the strength of their walls.

Actually some at least of such cells serve a double purpose for they also carry water in the plant (p. 134). Sometimes almost all of the cells of the stem are thickened. This is true in the giant bamboos which, while only a foot in diameter at the base, may reach a height of over 100 feet. Such a stem is a mechanical marvel which engineers would find it hard to

duplicate. The bamboo is a very interesting example of the use of a hollow cylinder. Engineers tell us that this is the most efficient use of materials: they do, of course, use just such an



A B

Fig. 31. Giant Cacti in the Arizona Desert (U.S.A.). A, Living specimens, about 25 feet high: the stems consist mainly of water-storing cells. B, A dead specimen in which most of the water-storage cells have been rotted away, leaving the woody skeleton exposed. [Photos: R.D.G.]

arrangement in the posts which hold up the overhead wires for trams and trolley buses. In most other stems which are not completely woody, the veins and other strands of strengthening materials are arranged as a hollow cylinder.

Large leaves of plants often contain strengthening ribs composed of veins plus fibres which are very similar in section

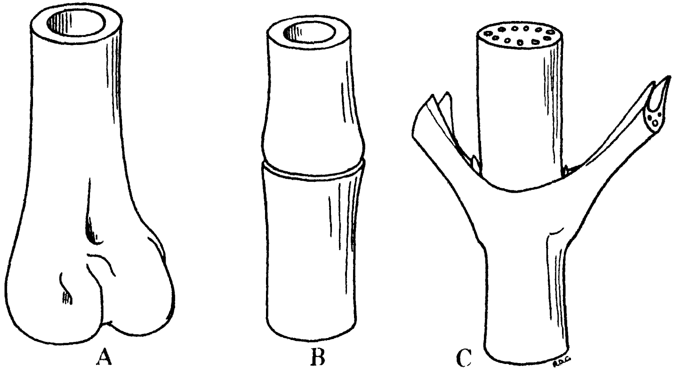


Fig. 32. Hollow cylinders for support. A, The lower part of a bone (femur). B, A piece of a bamboo stem. C, A piece of stem of a herbaceous plant, showing the arrangement of veins in a hollow cylinder.

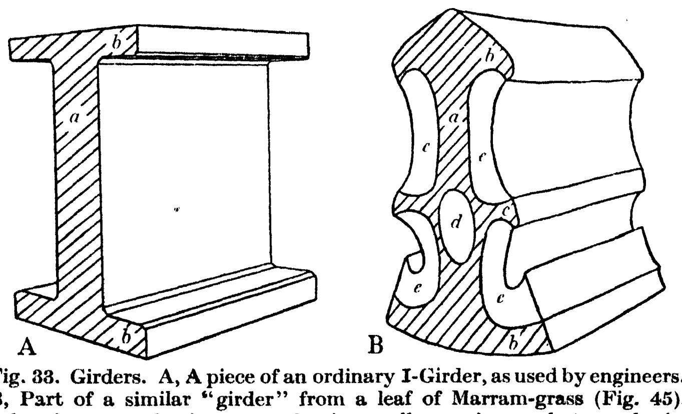


Fig. 33. Girders. A, A piece of an ordinary I-Girder, as used by engineers. B, Part of a similar "girder" from a leaf of Marram-grass (Fig. 45). *a*, *b* and *c*, strengthening parts; *d*, vein; *e*, cells carrying on photosynthesis.

to the **I**-bars used by engineers in bridges, etc. This is well shown in Fig. 33.

Plants whose stems go on growing thicker and thicker each

year add a new layer of wood cells around the old ones. Thus we get a mass of strong wood in the trunk and branches—and the inner part of this—the *heartwood*—is completely dead. It is interesting to compare the growth of bones (Fig. 147) in an animal with this thickening in trees and shrubs. Practically all bones are hollow cylinders and as a young animal grows its bones grow longer and thicker. Since the animal has to move itself and all its bones about, it is important that the bones be as light as possible and we find that as the bones increase in size the hollow within gets larger—the inner layers being eaten away. Trees do not move about and so weight is less important. Their inner parts do not as a rule break down as in the bones mentioned above, though, as we have mentioned in Chapter II, if the inner parts do decay the tree is often able to carry on for quite a long time.

THE MAMMAL SKELETON

If you examine the skeletons of a number of mammals (the hairy vertebrates) such as horse, rabbit, monkey, man, etc., you will find that they correspond almost exactly bone for bone. That is an example of one of the most important arguments in support of the theory of evolution, which suggests that all living things have evolved or descended from a few, or perhaps even one, simple original living thing. Actually the same general plan is found in all vertebrates—the skull and the backbone with the ribs, and the breast-bone if any, forming the main axis of the skeleton: the two pairs of limbs (fins, legs, wings or arms) with their girdles, which anchor the limb muscles, forming the appendage, or appendicular, parts.

THE BACKBONE

This is the foundation of the whole skeleton, "the tie-beam of the whole bony framework" as it has been called. It must be very strong, of course (one might compare it with the keel plates in the framework of a steel ship), but if the animal is to move freely the backbone must also be flexible. This is always the case since it is composed of a large number

joints, and there are also extra locking devices which counteract the greater danger of breakage in so flexible a backbone. Since man walks upright, strength rather than flexibility is the greater need and we find that the vertebrae do not rub on one another but are bound together by intervertebral discs of tough white cartilage which also act as shock absorbers—a very important function since the brain rests on top of the backbone and would be liable to concussion at every step if the jarring were not prevented by some such method.

At the bottom of the backbone in the human skeleton is the *coccyx*, a small piece of bone which appears to be three or four degenerate vertebrae joined together and which is really the vestige of the tail which our animal ancestors possessed millions of years ago. Such vestiges are further important arguments for the theory of evolution. The fact that a common pattern can be traced through a large number of different animals might be explained by supposing that they had all been created separately as "variations on a single theme", but the presence of useless vestiges such as the human coccyx and appendix (p. 100) which correspond to useful structures in other animals can only suggest that we share a common ancestry with those animals.

The Skull

The main part of the skull is the brain case or cranium. Joined to it are the ear bones, eye sockets and the nasal passage which is separated from the cavity of the mouth by the plate of bone known as the palate. The upper jaw is fixed to the remainder of the skull but the lower jaw-bone is separate, being hinged just behind the eyes. You will notice that the nasal passage opens into the back of the mouth. (The piece of flesh called the soft palate carries the nasal passage back a little beyond the end of the bony or hard palate: Fig. 60).

One of the most important differences between man and the other animals is the enormously greater intelligence which he possesses. This is rendered possible by the possession of a very much larger brain case. If you compare the skull of a rabbit, sheep or dog with that of a man (especially if you can examine skulls cut in half) you will see that whereas in the

skulls of such animals the brain case is confined to a small part at the back of the skull, in man the brain case is so large that it arches right over the rest of the skull making the slope of the face almost vertical instead of more nearly horizontal as in most animals.

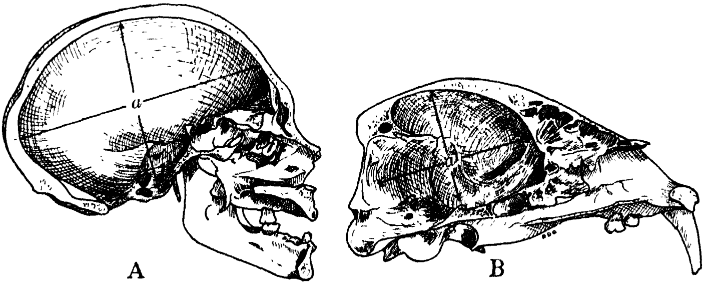


Fig. 36. Half-skulls of (A) Man, and (B) Jaguar. These two animals have approximately the same body-weight. The capacity of the brain cases (*a*) of the specimens drawn, however, were 1260 c.c. and 260 c.c. respectively!

The Ribs and Breast-bone

The ribs are hinged to the backbone, each pair being attached between adjacent vertebrae, and fixed to the breast-bone by strips of flexible cartilage. We have already spoken of the protection which such a cage affords and shall have more to say about the ribs when we come to deal with breathing (p. 157).

The Limbs and Girdles

Each pair of limbs is built on the same plan. Starting from the body there is a single bone, a pair of bones side by side,[1] then a set of small bones forming the very flexible joint of the wrist or ankle (or strictly speaking, in the latter case the back half of the foot) and finally the rows of bones in the palm and fingers or the sole and toes. In man the twin bones in the leg running from knee to ankle can twist round one another only a little, but the corresponding bones—*radius* and *ulna*—in the arm are so hinged that they can twist over or under each other

[1] See reference to kneecap on p. 66.

almost completely, thus enabling us to turn our hands round in a way that most animals cannot do. Quite obviously an animal like a rabbit which has to run over uneven ground would actually be at a disadvantage if its front feet were liable to twist as our hands do: the fact that the rabbit's radius and ulna are fixed together would seem to be a definite advantage in that case. For man, on the other hand, the ability to turn the hands and to make the thumbs work in the

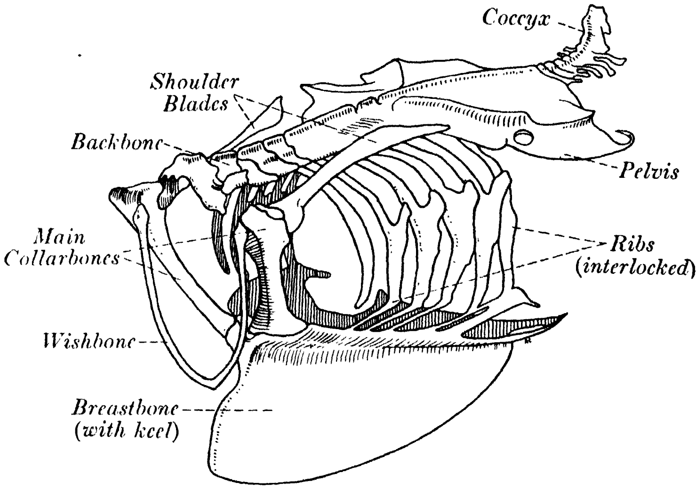


Fig. 37. The bones of the body of a Pigeon.

opposite direction to the fingers enables him to handle things much more easily than most animals can, and since the ability to use tools was one of the first things that distinguished man from the brutes, these details are an important part of our equipment for human life.

The whole weight of the body has to be transferred from the backbone to the legs by means of the pelvic girdle and we are not surprised, therefore, to find that the hip bones form a strong circle of bone (bowl-shaped to accommodate the intestines) firmly fixed to a part of the backbone that is com-

posed of three or four vertebrae joined together to form a specially strengthened *sacrum*. The pectoral girdle at the shoulders does not have to take so great a strain and we find that the shoulder-blades merely lie behind the ribs and are not joined to them or to the backbone.

The collar-bones take the strain of the muscles which move the arms from the "sideways swing" to the "forward swing" position, preventing the shoulders from coming towards one another when those muscles act. In an animal such as a horse which can move its legs (practically speaking) only directly forward and backward there are no collar-bones. In birds the muscles which we are considering are among the most important in the whole body, being those which pull the wings down in flight; and we find that here there is an extra set of collar-bones (popularly known as the *wish-bone*) in addition to the normal pair, a very large breast-bone and a specially strengthened cage formed by the ribs being locked to one another.

The Joints

There are over two hundred joints in the human skeleton, and in connection with these two problems arise. The bones must be able to move freely on one another without friction but they must not be able to move to such an extent that dislocation of the joint results. The second trouble is prevented by *ligaments*, or sinews, which form very tough fibrous connections between the various bones at each of the joints.

Where two or more bones meet at a joint, their rubbing surfaces are covered by thin layers of *cartilage*, a smooth, slimy, white substance which is easily seen when an uncooked knuckle of veal, or similar joint, is cut up. Obviously this cartilage very materially lessens the friction at the joints. As it wears away it not only degenerates into a slimy *synovial fluid* which forms a perfect natural lubricant but also, being a living substance, repairs itself and so maintains a constant thickness. The synovial fluid is kept within *capsules* or bags of skin, and so is kept in its place. Similar capsules, filled with synovial fluid, are also found where tendons attached to

muscles (p. 66) are liable to cause friction by rubbing on other tissues in the body.

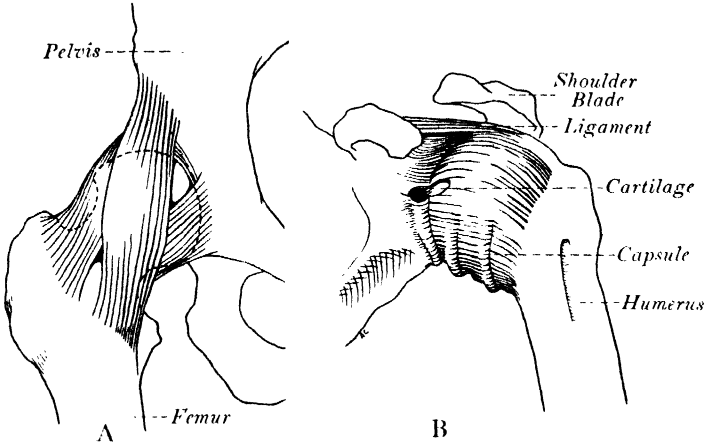


Fig. 38. Joints. A, The hip joint, to show the main ligaments. B, The shoulder joint with its capsule partly opened to show the cartilage layer.

TEETH[1]

Most vertebrates (except the birds) have teeth and in most cases the teeth are all of one type—sharp-pointed cones—and have only the one function of holding the prey once it has been caught. In most of the mammals there is a higher degree of specialisation and a differentiation for different functions. Thus there are single teeth for biting the food into portions and double teeth for chewing so that the food is not swallowed whole. (You will realise how much better this is when you think of the different ways in which a snake and a lion eat their food.) In addition, the teeth—and even the hinging of the lower jaw—are differentiated according to the type of diet with which we have to deal.

[1] For detailed structure, see Fig. 161, p. 263.

Carnivorous mammals like the dog have teeth specialised for cutting flesh. The front teeth are sharp and chisel-like while the back teeth are flattened sideways and bear sharp points and ridges. The teeth of the upper and lower jaws meet exactly except for a pair on either side (called *carnassials*) which overlap and so are capable of scissor-like action. If such teeth are to function properly there must be little or no side play in the movements of the lower jaw (you know how inefficient a pair of scissors can be if the blades are loose). Actually the hinge of the lower jaw fits so closely into a deep transverse groove at the back of the upper jaw that no side play is possible.

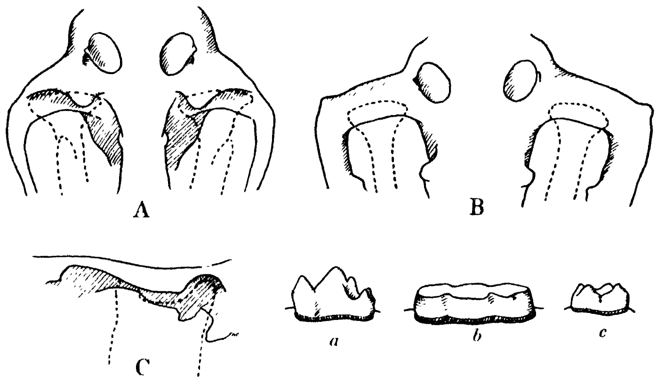


Fig. 39. The lower jaw hinges and representative double teeth in—A, *a*, dog; B, *b*, cow; C, *c*, man. [A and B, drawn from below; C, drawn from the side. The position of the lower jaw is shown by broken lines in each case.]

Such specialisation would be of little use to herbivorous animals like sheep and cows. These need to chew their food with a grinding movement, rubbing the grass, etc., between their teeth with sideways movements of the jaws. The hinges of their lower jaws are mere flat surfaces which allow plenty of lateral movement. The double teeth are wide and their surfaces are worn flat by the continual rubbing. The easiest way of biting off portions of plants is by tearing and we find that herbivorous animals usually have front teeth specialised to act as vices. Sheep and cows have a hard pad in place of

front teeth in the upper jaw and the corresponding teeth of the lower jaw are crowded together and project forward in such a way that they grasp the leaves very firmly.

Man shares with monkeys, apes and pigs an omnivorous appetite and his teeth are intermediate in type between those of carnivores and herbivores. The front teeth are broad and chisel-shaped while the back teeth are wide but with small points and ridges on them so that they can deal with a wide variety of food materials. The hinge of the lower jaw is of the ball and socket type and while normally the jaws meet exactly enough for cutting purposes the hinge is capable of slight dislocation and so allows lateral movement when necessary.

PRACTICAL WORK

1. Notice how a jelly-fish "flops" when stranded on the beach or when held in the hand: it is no longer buoyed up by the water. Notice, too, how limp seaweeds become when removed from the water.

2. Put some cut shoots of plants in water and leave others lying in the air. Which wilt? What do you notice about leaves which have completely wilted which suggests that lack of water is responsible for the change? Weigh each shoot before and after the experiment.

3. Take a thick stalk of rhubarb and bore carefully into one end of it with a cork-borer, without detaching the boring.

4. Split a stalk of dandelion, rhubarb or growing elder upwards into four (Fig. 44). Your results should show you that the cells inside are turgid, while the outer skin is tight. Put the stalks so treated in either pure water or strong sugar solution: do the results then obtained support the view that the strength of the cells is due to turgidity?

5. Kill an earthworm by drowning it in methylated spirits. Notice that it is rigid and still retains its shape. Cut it carefully along the back to let out the "coelomic liquid" which is present between the body wall and the food canal. Does the worm still retain its rigidity?

6. When "cleaning out" a rabbit or a chicken notice the skins of connective tissue which hold stomach, intestines and other organs in place. If an uncooked joint of veal is cut up it is very easy to see the thin white skins of connective tissue and also the pure white cartilage on the rubbing surfaces of the bones.

7. Examine the hard, horny covering which is the skeleton of a beetle. You can remove the soft parts of a dead beetle by boiling it in strong caustic potash solution for a few minutes and then rinsing it in clean, cold water. Examine other insects and also crabs, lobsters, shrimps, prawns, centipedes, millipedes, etc.

8. In a rabbit stew, find two or more consecutive vertebrae, separate them and notice the spinal cord which runs through them, and the way in which they are locked together. Compare with the vertebrae of a snake.

9. Try cleaning up bones from the family joints or from a whole rabbit. Prolonged boiling will make the flesh very soft. It can then be removed easily and the bones scrubbed with a nail brush and soap. Note that certain of the larger bones (e.g. femurs) may break up by the disintegration of the growth-pads (Fig. 147). Form your own collection of loose bones: see how they fit into the complete skeleton by comparing them with the bones in a mounted skeleton.

10. Compare the mammal skeletons in a museum one with another.

11. Watch the movements of the lower jaw in dog, cow, man, etc., and examine the hinging of the lower jaw in prepared skulls. Carefully examine and compare the structure and arrangement of the teeth also.

CHAPTER IV

MOVEMENT

Movement of Protoplasm

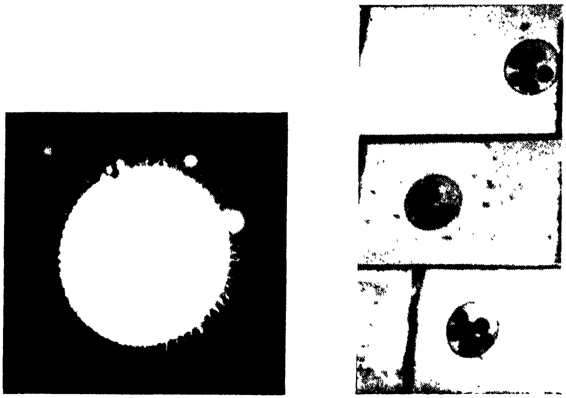
Movement, in some form or other, is a characteristic of all living things. In an earlier chapter we discussed Amoeba as an example of a living thing composed of pure protoplasm and we pointed out that the animal moves and engulfs food by a streaming movement of its protoplasm. This *amoeboid movement* is probably the simplest of all movements (though we cannot fully explain it!) and we shall return to it in discussing the way in which the white corpuscles of the blood deal with bacteria (p. 267).

In larger animals the protoplasm as such does not move about; but in some plant cells there is a streaming movement of the protoplasm which is known as *cyclosis*. This consists of a circulation of the living material within the cell and is particularly well seen in the slender strands of protoplasm which often stretch across the vacuole of the cell (Figs. 22 and 23).

Another simple type of movement is that of tiny whips of protoplasm called *cilia*. These can be seen working in the nephridia of an earthworm (p. 12) or on the gills of fresh-water or marine mussels. If living portions of these are mounted in water on a microscope slide and examined under the high power of the microscope the twinkling movements of hundreds of cilia will be seen. The addition of a little Indian ink to the water will show the currents which the cilia set up. Each cilium lashes the water in one direction and recovers its original position without pushing the water back in the opposite direction, but it is not possible to follow this "beating" with the unaided eye. The photographs in Fig. 41 will help you to understand how the cilium does this.

In the examples mentioned above the cilia cause movement of water inside the organism. In small organisms, however, such as bacteria, tiny aquatic plants, etc., the

beating of the cilia results in movement of the whole creature through the water. This is well shown in the case of *Volvox.*



a *b*

Fig. 40. *Cilia.* *a*, *Volvox* ($\times 20$), a small spherical green plant which swims by the co-ordinated beating of thousands of cilia. This individual was photographed by reflected light against a dark background by Prof. F. E. Lloyd. *b*, Photographs from a cinema film by Prof. Lloyd. You can see how the Volvox has changed its position.

In larger organisms movements of the whole body or of its parts are more important than movements within the protoplasm, though in all cases the protoplasm is responsible in one way or another for the movement.

Movement in Plants

Plants rarely show the active movements that we find in animals. The majority of an animal's movements are definitely directed towards satisfying the animal's needs in the way of capture of food or of escape from enemies. Plants do not hunt for food—with rare exceptions they obtain their raw materials from the air and from the soil—and since this last fact means that they must usually be rooted in the ground

they cannot move to escape from enemies. Roots must penetrate to considerable depths in order to obtain water and, if the plant is large, to anchor it securely in position, while the leaves

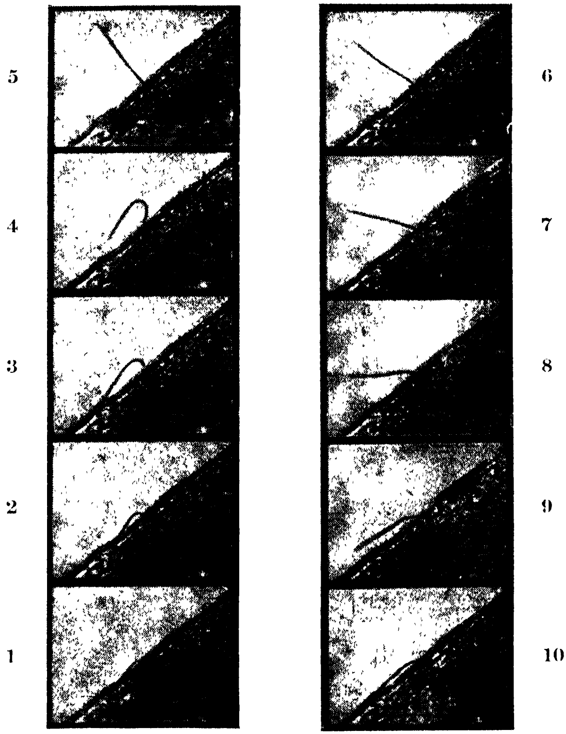


Fig. 41. *Cilia.* Movement of a single cilium on the gill of a mussel: notice how it moves up like a whip-lash and down like a solid rod. The cilium is 0·07 mm. long and the pictures were taken at intervals of $\frac{1}{10}$ second. [From a cinema film by Dr J. Gray.]

must be spread to absorb a large amount of light. Such adjustment in space need not be rapid and so it can be achieved by the slower processes of growth. We shall have occasion to discuss this at greater length in Chapter XII.

There are, however, some cases of comparatively rapid movement in plants, though these are movements of parts rather than of the whole organism. We know, for example, of *sleep movements* in plants. Such flowers as the common daisy

Fig. 42. A specimen of the sensitive plant (*Mimosa pudica*), one of whose leaves has been touched. [Photo: R.D.G.]

and the water-lily close at night, as do the leaflets of wood-sorrel, clover, etc. The sensitive plant moves its leaves when touched (as well as at night), while the marram-grass, which grows on sand-dunes where water is sometimes difficult to obtain, rolls its leaves up tightly when short of water and so reduces loss of water by evaporation.

In the case of the sensitive plant and in the carnivorous plants which capture insects and other small animals (Chap. VII), the movements are rapid enough to be seen by the naked eye. Another case of rapid movement in plants is provided by the opening of the flower of the evening primrose—a most fascinating thing to watch in the dusk of a summer evening. The dropping of the sepals, as sudden as the fall of a railway signal, and the opening of the petals in a rapid succession of jerks are very remarkable. Probably no other flower provides such a dramatic opening.

One very interesting fact about some plant movements is that, as in animals, ether and chloroform will anaesthetise the organism and the movement will not take place until the effect of the anaesthetic passes off.

Mechanism of Movements in Plants

There are no such things as muscles in plants. Such movements as do occur are usually due to changes in turgor (p. 34)

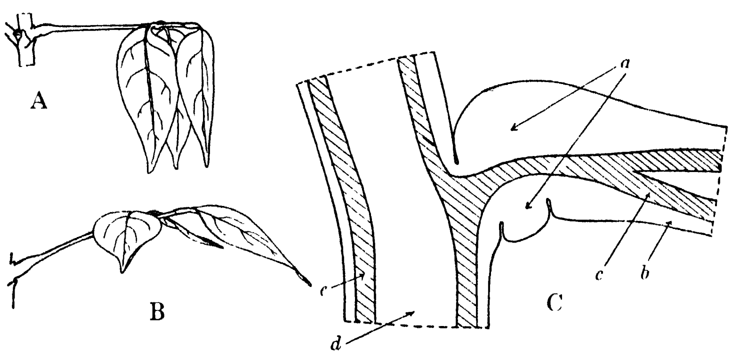


Fig. 43. The *pulvinus* of a bean leaf. A and B, Night and day position of leaf. C, Section through the leaf base. *a*, hinge cells of the pulvinus; *b*, leaf-stalk, and *c*, its vein; *d*, stem, and *e*, its vein.

of certain thin-walled cells. In some cases there are many of these cells grouped together to form a sort of hinge as in marram-grass or a large *pulvinus* as seen in mimosa and in the common runner-bean.

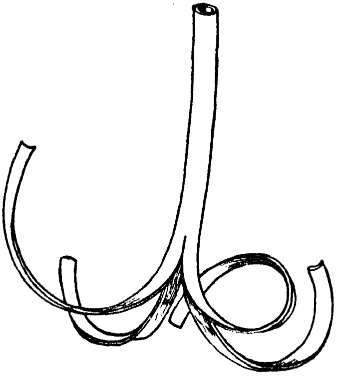


Fig. 44. Dandelion stalk, cut ready for experiment.

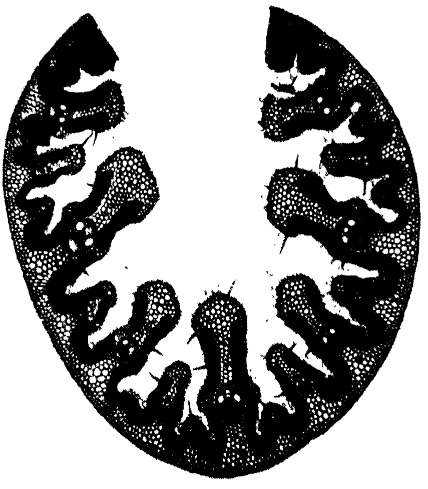


Fig. 45. Section through a leaf of Marram-grass in a dry condition—i.e. rolled. The dark areas are composed of the cells whose turgidity changes with changing conditions. [Photo: R.D.G.]

The way in which changes in turgor may lead to movement may be illustrated by experiments with the stalk of a dandelion flower. This has an outer, rather inelastic, skin over living turgid cells placed around the central hollow. When the stalk is slit into four part-way from the base the pressure of the sap in the inner cells forces them to expand. The outer skin does not expand and so the four pieces curl outward. Usually the cells are not fully turgid and if the slit stalk is placed in water they absorb more water and swell still further—resulting in increased outward curling. If now the water is replaced by a strong salt or sugar solution the cells lose water by osmosis and shrink. The outward curling will then decrease and the slit pieces become straight or may even curl inwards.

In marram-grass when the hinge-cells are turgid the leaf is flat and when they lose their turgidity they cause the leaf to roll up. What it is that controls the changes in turgidity we do not know (though we may bring about such changes easily enough with water and salt solutions, as we have seen in the experiments with the dandelion stalk). It is just as well that you should have this example (and there are many others) of something of which science is ignorant. The essence of science is its continued search for the "why and wherefore" and, while we already know much, there is still a lot to be discovered. If you continue to study science long enough you may be able to help in the search.

Movement in Animals

Animals move in various ways, of which swimming, walking and flying are the most obvious. Fish are streamlined—rather blunt in front and tapering behind as are racing cars and aeroplane bodies and the underwater parts of modern ships—and this is the shape that offers least resistance to rapid movement. Flatfish, such as plaice and rays, are very much flattened horizontally, while other fish are laterally compressed to a slighter extent so that their sides present a fairly large surface to the water. This large surface in both types of fish is important in giving a good grip (by friction) on the water when swimming. (The fins are used only for balancing.)

Practically the whole of the body of a fish is bone and muscle, the coelom being comparatively small. The swim-

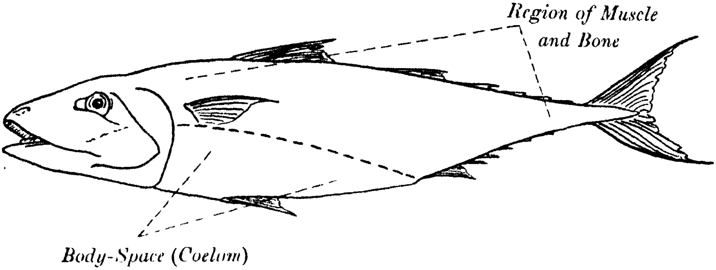


Fig. 46. A typical fish, showing the extent of the muscles.

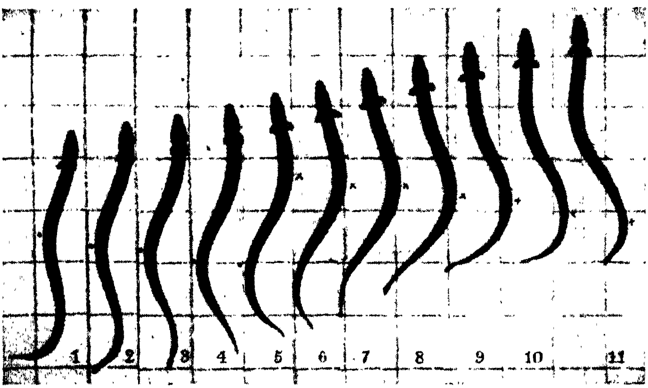


Fig. 47. Movements of a butterfish in swimming. The photographs were taken at intervals of $\frac{1}{20}$ second and then pasted side by side. The side of each square is 1 in. Note how the muscular waves (marked by dots and crosses) pass down the body: these waves increase in vigour as they approach the tail. [Photos: Dr James Gray.]

ming movement is a sinuous or wavy one: the head turns slightly from side to side and thus initiates waves of muscle movement. These waves pass backward along the whole body, often becoming more powerful in the tail region. Thus the

fish tends to press the water backwards and as the fish can move more easily than the water the fish is propelled forward, just as a rower by trying to push back the water with his oars only succeeds in moving his boat forward. In all cases, of course, some water is pushed back and creates the wake of the moving object.

The movement of a snake is very similar to that of a fish, though the very long thin body can make far wider sweeps than the much more compact body of a fish. Instead of having

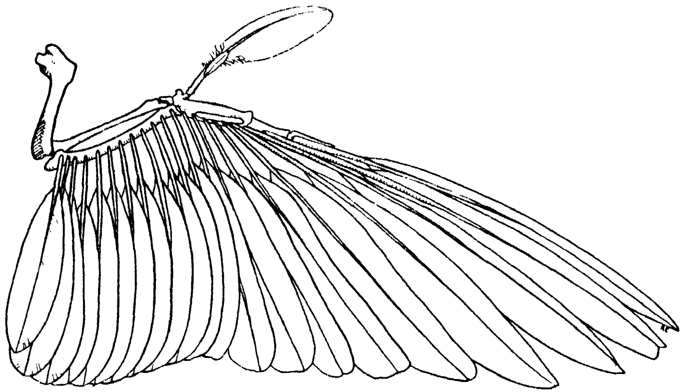


Fig. 48. Bones and main feathers of a bird's wing. Note the small "bastard wing", which corresponds to the thumb of the human hand.

a large area of flattish sides and fins, a snake gets its grip on the ground by means of large scales, with backwardly-directed points, on its underside.

The wings of a bird consist of feathers attached to bones which run along the front edge of the wing. The feathers are fitted together in such a way that the parts which overlap one another make a rigid air-tight surface when the wing is being depressed but not when the wing is being raised again. Thus the beating of the wings tends to lift the bird and the wing surfaces cut through the air obliquely so that they push the bird forward as well. Very powerful breast muscles move the wings up and down (p. 48). Insects and bats probably rely

for lifting power on the fact that a *quick* beat down pushes them up far more powerfully than a *slow* beat upwards pulls them down again.

Fig. 49. Wings—and feet and tail!—in action: a Gannet about to land on its nest. [Photo: Niall Rankin.]

Many birds can take advantage of upward currents of air and maintain themselves in an effortless, soaring flight without any beating of the wings; and, in recent years, men have successfully used gliders to imitate such flight. The flight of so-called "flying fish" is merely a glide of this type, for the fish has no muscles powerful enough to beat the large fins which are used as wings. The motive force for the glide is

the power with which the fish leaps from the water—power derived from the action of the back and tail muscles (see Fig. 46). As the fish leaves the water, the "wings" certainly quiver—but it is not known whether this is an accidental result of any unsteadiness on the part of the animal at this time or is a deliberate action designed to shake off drops of water or to help keep the animal's balance.

There is little we can say of running and walking beyond the fact, which we have already pointed out (p. 38), that the limb bones act as levers, by means of which the muscles secure

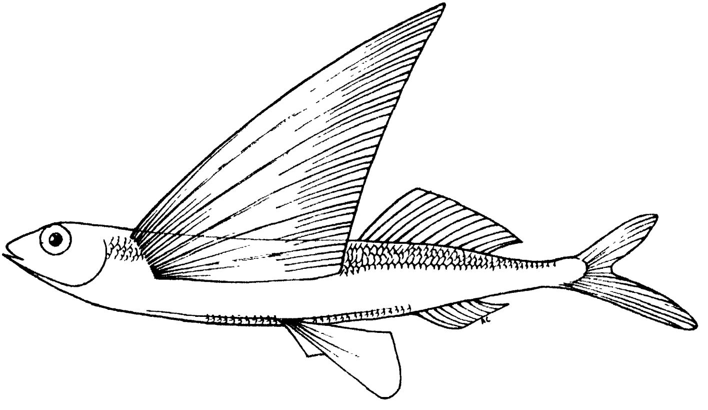


Fig. 50. A Flying Fish. Note the extremely large pectoral fins, which are used for gliding.

their grip on the ground. All very fast-running animals (e.g. horse, giraffe, ostrich) run on the tips of their toes and have the running muscles bunched high in the leg so that their legs act as very long, light levers. Animals, such as grasshoppers, frogs and kangaroos, which hop, usually have far larger and more powerful back legs than front legs.

Muscles

Muscles are the lean meat in the animal body; and, next to the skeleton,probably the bulkiest part of the body in most animals—as you will realise if you think of the appearance of

carcases hanging up in butchers' shops. With the exceptions of amoeboid and ciliary movements which we have already mentioned, all animal movements are due to the contraction of muscles.

We say "contraction" and this at once brings out one important point, namely that muscles can only pull: they cannot push or even stretch themselves out again to their original

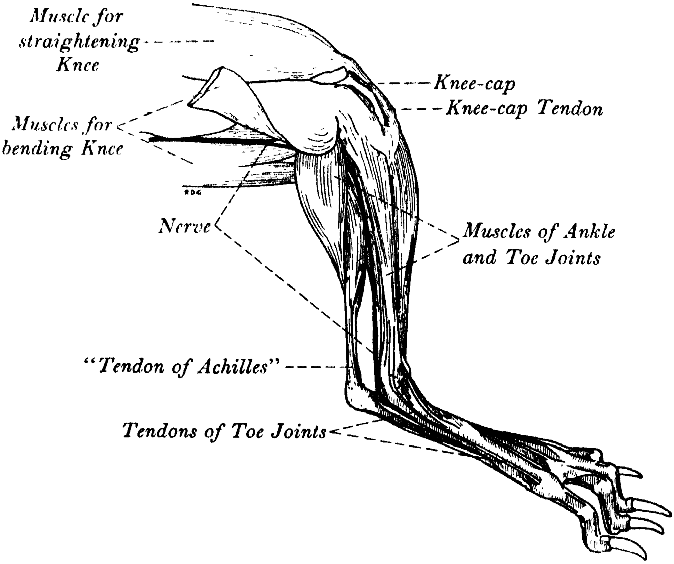


Fig. 51. Dissection of a back leg of a rabbit to show the main nerve, muscles and tendons.

length. Therefore we find that in most cases—certainly wherever muscles work the joints of the skeleton—there are pairs of opposing muscles or even paired sets of muscles. Thus the well-known biceps muscle in the upper arm is responsible, with others, for bending the elbow joint, but once it has performed that movement it is powerless to do anything else. It is necessary for the triceps and other muscles *behind* the

humerus not only to straighten the elbow but to extend the biceps muscle again.

In the eye you can see a set of coloured muscles called the *iris*, surrounding the pupil (which is really a hole through which light reaches the back of the eye). Muscle fibres in the iris are arranged radially and when these contract the pupil is pulled more widely open. An opposing set of muscles form a ring around the pupil and when they contract the diameter of the pupil is lessened.

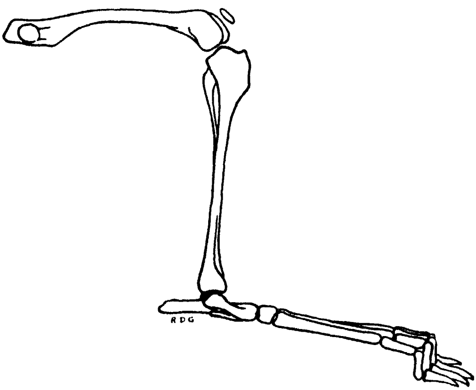


Fig. 52. The bones of the back leg of the rabbit. (For comparison with the figure on the opposite page.)

In some cases muscles are not opposed by other muscles but work against some other opposition. Thus oysters and other similar shell-fish have powerful muscles for closing their shells but for opening them they have to rely on the elasticity of the rather leathery substance which forms the hinge joining the two shells. Similarly, if the muscles around the human abdomen contract, the weight and pressure of the stomach and intestines will push them out again when they have finished their effort. In later years, if these muscles are allowed to become slack through lack of exercise, the weight of the contents of the abdomen may be too much for them—with unfortunate results as far as the "figure" is concerned!

Within the body the tubes which form part of the food canal and the arteries (and to a lesser extent the veins) are elastic, the elasticity being due to muscle fibres arranged in rings and contracting against the pressure of the food or blood inside. Particularly important in this connection are those thick rings of muscle called *sphincters* (Fig. 63), which stand at the entrance and exits of the stomach and intestines—contracting so strongly that until they relax no food can pass.

Most of the larger muscles of the body, i.e. those that work the joints, are more or less cigar-shaped and are very firmly anchored at each end by means of tough *tendons*. In some cases these tendons are very short and the muscle fibres themselves appear to be fixed almost directly on the bone, but in other cases the tendons are quite long. As examples we may point out the tendon of Achilles at the back of the ankle, the two tendons at the back of the lower end of the thigh, and the tendon by which the muscle on the front of the thigh reaches over the front of the knee and is fastened on to the top of the shin bone. This last tendon is in a very exposed place and so is very liable to injury. We find, however, that it is strengthened by a piece of bone, the *kneecap*, which actually grows within the tendon and runs in its own groove on the femur.

Some muscles are situated quite a long way from the joints they move. Those responsible for the movements of fingers and toes are to be found near the elbow and in the calf respectively. If you bare your arm to the elbow and move your fingers to and fro you can quite easily see the movement both of the finger muscles below the elbow and of their tendons lower in the arm. The same thing is true of many other animals and you can find the appropriate tendons and manipulate the toes in a foot cut from a dead hen.

The Chemistry of Muscle Action: Fatigue

Muscles work—there is no doubt of that—and to perform their work they need energy. This energy is obtained from the chemical changes of respiration, which for muscles involve the oxidation, or slow burning, of *glycogen*, a substance not unlike starch. We all know that the faster we run or swim the more

oxygen we need and when we have given our muscles a lot of exercise we feel hungry.

The exact changes which take place when a muscle works have been studied in recent years by using single muscles taken from recently killed frogs. It was soon discovered that for a time at least a muscle can keep on contracting as well without oxygen as with it. If it is made to contract again and again without oxygen, however, it gradually does less and less until finally it ceases to work at all. Administration of oxygen then causes it to recover its capacity for work. Studies of single contractions have also been carried out. It was found that after each contraction there is a period of recovery and that oxygen is used up and carbon dioxide given out during this recovery stage, but not during contraction.

It would appear that when a muscle contracts a number of chemical changes occur, resulting in some of the glycogen which is stored up in the muscle being turned into lactic acid, which is the acid present in sour milk (p. 261). In the recovery stage, part of this lactic acid is oxidised to carbon dioxide and water and the energy obtained is used to convert the rest of the lactic acid back to glycogen. The muscle can contract again and again, even though it has not fully recovered, and so increase the amount of lactic acid in itself until that amount is about 1/300 of the weight of the muscle: then further contraction is impossible and the muscle is said to be "fully fatigued". Not until some of the accumulated lactic acid is oxidised away can contraction start again.

This explains why (unlike an engine) we can "sprint" a short distance at a much higher speed than we can run a long distance. If we run at such a speed that we can oxidise the lactic acid as rapidly as it is formed, we ought (provided that we are really fit) to be able to keep on almost indefinitely. On the other hand if we want to do our best in a race, we can run much faster than that but we must be careful not to run so fast that our muscles accumulate enough lactic acid to stop them working before the end of the race. Good athletes at the end of a fiercely-contested race are usually "run out"—but it does not matter then, for they can lie down and recover, gradually oxidising away the lactic acid in their muscles. In

a short sprint race we can go "all out" from the beginning but in a longer race we must go more slowly at first—oxidising the lactic acid as it is formed and sprinting only towards the end.

Another point which arises from the chemistry of muscle action is the importance of relaxation. Since the lactic acid formed during contraction is oxidised away most readily when the muscle is resting, the athlete who develops most staying power is the one who can acquire to the greatest degree the art of relaxing all muscles not in actual use. A suitable illustration of this is furnished by the crawl stroke. When this was first attempted by white people—it was "imported" from the Fiji Islands—they found it so exhausting that it was used only as a short sprint at the end of a race and beginners at the stroke to-day, even though they are experts at other strokes, find much the same difficulty. Those swimmers, however, who have learned to relax properly when using this stroke can keep it up for quite long distances—in fact, Gertrude Ederle swam across the English Channel in record time, using the crawl the whole way.

The Value of Exercise

The primary value of exercise lies in strengthening and developing the muscles, and since in vigorous exercise the muscles require more oxygen than normal, deep breathing is necessitated. In ordinary breathing we rarely use more than the top portion of our lungs and, if we never have occasion to breathe deeply, the rest of our lungs gradually harden and become useless. Exercise which involves deep breathing will not only strengthen the lungs but will stretch them so that their capacity is increased to the utmost.

Vigorous exercise also necessitates an increased flow of blood and not only is the heart thus developed and strengthened but every other part of the body—brain, food canal, liver, kidneys, etc.—benefits. The whole "tone" of the body is improved.

Exercise is much more effective if it is carried out in the fresh air, for fresh air has a tonic effect on the skin (p. 182), and deep regular breathing is the best way of keeping the nose,

throat and air passages of the thorax healthy and one of the best preventives of colds and catarrh.

The best types of exercise are those free activities which involve all the muscles of the body. We would therefore commend vigorous walking (not a mere sauntering stroll), swimming, running and games which involve them. Organised physical training and gymnastics are of value in preventing and correcting faulty attitudes of body, and in acquiring and developing habits of self-control, discipline and quick response; and country dancing can also be very good exercise, as those who have tried it will know.

Biology and Athletics

Success in athletics depends on a number of biological factors and, while we can alter some by "training", others are beyond our control. We have already pointed out why a horse can run rapidly: it is equally obvious that a duck with its heavy body, short legs and flat feet is not built for speed on land. In the same way individual boys and girls start with initial advantages or disadvantages. These are not confined to points of "build" but extend to such factors as size of heart and lungs. The great Finnish runner Nurmi is said to have a heart of twice the normal capacity and you will realise what an advantage that is in pumping as large a supply as possible of oxygen-laden blood to the muscles. All good athletes have large lung capacities and it is also believed that most of them have unusually thin walls to the air sacs of the lungs so that oxygen passes into the blood with unusual ease and rapidity.

The most important factor for success which is within our control is our style. The ability to get the most out of a strong supple body needs a really good style. Every movement in athletics, whether it be in running, swimming or jumping, involves many muscles and each detail of the movement must fit the other parts of the movement perfectly if the style is to be good. If the style is awkward or confused we shall not get the best results from the efforts we make: maximum speed or maximum height and length in jumping will only come from neat, rhythmic and carefully perfected style. The same thing is true of the very precise movements required in diving,

batting in cricket and similar branches of athletics. To get a good style the best thing is to watch the finest athletes we can see— and watch every little detail of their movements, especially what is common to them all, till we know them well enough to copy them. The services of a trainer who knows the best movements himself is of great value for he is able to see our faults of style much more easily than we can ourselves.

Once a good style is attained, we must practise and practise until we make it automatic. It is said that "Practice makes perfect". This is true only if the style is perfect before the practice begins. If it is faulty to begin with, practice will only fix the faults so effectively that it will be almost impossible to eradicate them afterwards. The proverb should be "Practice makes actions automatic" and so we would say again—*practise only after the style has been made perfect.*

In training, we should not confine ourselves to the particular exercises or athletic events which interest us most, for a variety of exercise helps to keep all our muscles fit. While sprinting increases the speed of muscle movements, longer runs and long walks develop and strengthen the heart and lungs enormously and so increase our powers of endurance.

Finally, we would suggest that while success in athletics may be very pleasant, it should not be regarded as an end in itself. It may be to many people—the modern popular attitude is to assume that it is—but as biologists we should look upon athletics as means to the attainment of perfect fitness. Over-specialisation may easily lead to an unwelcome over-development of certain muscles and the over-straining of heart and kidneys, and while specialisation may give spectacular results it is a moderate and diversified indulgence in physical exercise and athletics which develops the degree of health and grace we all desire.

PRACTICAL WORK

1. Watch an actively moving Amoeba under the microscope and draw it at 2-minute intervals.

2. Remove a nephridium from an earthworm recently killed by immersion in alcohol, put it in water on a microscope slide and notice the cilia working within it.

3. Remove one shell from a living fresh-water mussel, put it in a dish

of water, turn back the "mantle" within and sprinkle fine iron filings, or starch grains stained in iodine, on the gills. The movements of the cilia which move the filings will be visible if a small piece of the gill is examined in water under the microscope.

4. Look for movements in plants, such as those described in this chapter and in the section on plant behaviour (Chapter XII). Watch the opening and closing of the flowers (the water-lily is particularly good). If possible, visit a greenhouse at night, switch on the lights and watch the gradual "awakening" of plants which show sleep movements.

5. Carry out the experiment with the dandelion stalk, as described on pp. 51 and 59.

6. Study examples of animal movement, noting the *details* carefully, e.g. fish swimming, horse running, bird flying or gliding.

7. If you can obtain the wing of a dead bird, examine its structure carefully, noting the position of the bones and the overlapping of the feathers.

8. To study the effect of streamlining, attach a spring balance to a dead mackerel or other fish and tow it through the water. Note the resistance offered by the fish at different speeds. Repeat the experiment after cutting off the head or the tail—or both—and compare the results.

9. Remove the skin from the breast of a dead bird. You will find that the breast is a mass of dark red muscle fixed on to the big shield-shaped breast-bone, the central ridge or "keel" of which separates the muscles of the left and right sides. With a scalpel cut these muscles away from the ridge and then cut them away from the main part of the breast-bone except at the outer front corners where they are attached by tendons to the wings. You will find that you have a pair of muscles on each side: the larger one in each case pulls the wing down and the smaller one pulls it up again.

10. Note the position of the fins in a fish, and in cleaning one note the extent and position of muscle and bone. Skin part of the side and note the arrangement of the muscles.

11. The muscles working the toes of a bird are at the top of the leg and are connected to the toe joints by long tendons. Take a leg cut from a dead chicken, find the tendons and pull them to work the toes and open and close the foot.

12. Bare your arm to the elbow and move your fingers. You can follow the movements of the muscles under the skin just below the elbow and of the tendons nearer the wrist. If you spread your fingers out straight and as widely as possible you can trace across the back of the hand the tendons which are straightening the fingers.

13. Dissect the back leg of a rabbit, including the hip-bone and muscles attached. Carefully remove the skin from the leg and foot: this will not be too easy but it is safe to tear it away even with considerable force. There is a certain amount of connective tissue which can easily be removed and the separate muscles with their tendons will then be seen. The tendons are much stronger and *glisten* more than the connective tissue so that it should not be difficult to tell which is which.

CHAPTER V

FOOD AND THE FEEDING OF GREEN PLANTS

The Necessity for Food

Actively living things require food. We say "actively" living because activity varies greatly from time to time. Some animals like the frog are dormant and completely inactive throughout the winter, many trees shed their leaves in autumn and rest till the spring and most other plants which live for more than one season "die down" and remain dormant for part of the year. All of these stop taking in food from without during their period of inactivity and use *very* little of the food which may be stored within them.[1] Extreme cases of such inactivity are seeds which have been shown to be alive after storage for a hundred years (p. 163) and a snail (in the British Museum !) which was believed to be dead but which was found to be alive after being stuck on a card for three years.

This suggests that at least one reason why food is necessary is to supply the living thing with its *energy*—that is, the power to move about and to do various kinds of work. Since animals are far more active than plants they require much greater amounts of energy or "fuel" foods and in fact a fully-grown animal uses practically all its food for this purpose.

A living thing which is still *growing*, however, must obviously use some of its food for body building. Plants use a great deal of their available food for making new parts—i.e. for growth—and animals, such as caterpillars or young birds, which grow rapidly, require large quantities of food. It has been estimated, for example, that the silkworm caterpillars which hatch from an ounce of eggs consume a ton of mulberry leaves before they are fully grown and ready to spin their cocoons.

Even when growth has finished, a little food will still be needed to make good the general wear and tear of the proto-

[1] In plants, the food thus stored is used for renewed growth in spring.

plasm and for repair—e.g. when a bone is broken, a muscle torn or when certain parts of the body, wasted by illness, are in need of healing and rebuilding. Growth of new tissue to cover wounds is well illustrated in plants (Fig. 154).

Food Storage

In many cases only a part of the food obtained or made is needed for immediate use and the surplus is *stored* for future

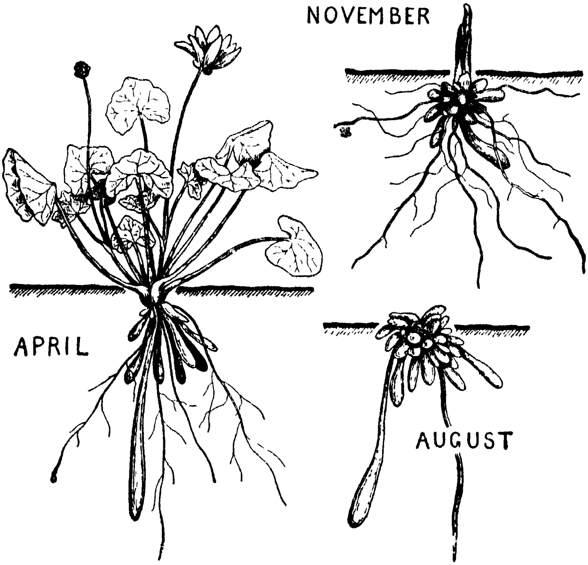


Fig. 53. Lesser Celandine plant at various seasons of the year. Note the special storage roots. (× ½.) [From Yapp.]

requirements. Most plants which live on from year to year—*perennials*[1]—make some provision for food storage: the storage roots in the lesser celandine are one example of this. Other plants, known as *biennials*[1] (e.g. carrot, turnip, foxglove), grow a flat rosette of leaves and a swollen root filled with

[1] By contrast, plants which complete their life-cycle within a single season are called *annuals*.

reserve-food during their first season and use this food during their second, and last, season in making a tall spike of flowers and seeds. Mammals store excess starchy foods in the liver (p. 102) and excess fat in layers under the skin (Fig. 113) and around the heart and kidneys.

Food is often stored up against the time when the living thing may be faced with shortage. Thus squirrels accumulate stores of nuts for the winter, while the native sheep of the South African karoos (semi-desert country) store fat in enormously swollen tails during periods of plenty for use in periods of famine. Plants which grow where water is scarce (not merely in deserts but on roof-tops and old walls) usually have thick fleshy leaves in which water can be stored (Fig. 105).

Again some food reserves are almost always included in eggs, seeds and other reproductive organs such as bulbs, corms and tubers. These will be discussed more fully in the chapters on reproduction and growth and we shall merely point out here that the food reserves are of great value in giving the young plant or animal a good start in life.

We ought also to add that food is normally stored in an insoluble form but has to be broken down—or digested—to a soluble form before it can be transported from one part of the organism to another. Thus glycogen stored in the liver and starch stored in plants have to be transformed to sugar for removal.

The Food Substances Required

The actual food substances which living things can use are limited. Protoplasm is a mixture of certain chemical substances, called *proteins*, and a solution of various salts in water, together with small quantities of other substances related to fats and sugar. As the source of energy, the substance usually used is *sugar*, though *fats* and proteins may also be used for this purpose, especially in animals. The main food requirements of *all* living things are, therefore, essentially the same—proteins, salts and water for growth, with sugar (and fats and proteins in some cases) for energy. To some animals at least, substances known as vitamins (p. 91) are also essential.

With water, salts and fats we are quite familiar but we must say a word or two about the other substances. The sugar which living things usually use for energy is *glucose*—$C_6H_{12}O_6$—and this is similar to, but not the same as cane-sugar—$C_{12}H_{22}O_{11}$. If you remember that C stands for an atom of carbon and H_2O for a molecule of water you will understand why these substances, together with starch—$(C_6H_{10}O_5)_x$—are classed as *carbohydrates*. Plants convert sugar to starch for storage and animals can with equal ease turn starch to sugar, so that a supply of starch is practically equivalent for food purposes to a supply of sugar.

Lean meat and white of egg are examples of foods which are mainly proteins (and water). Proteins are extremely complicated compounds, each molecule being built up of a large number of compounds called *amino-acids*. The proteins in the protoplasm of different species of living things differ apparently in being different arrangements of the various amino-acids. Enough of these amino-acids are known to make many million kinds of proteins and it is thus not altogether surprising that the different living creatures have each their own special varieties of proteins. Thus, there are certain proteins in grains of wheat and the hen which eats the wheat digests these proteins and in doing so breaks up the wheat-proteins into the amino-acids of which they are formed. Some of these amino-acids are then changed into other amino-acids and these, together with some of the original amino-acids, are built up by the hen into hen-proteins. These may then be stored up, with fats, as yolk in an egg and there used by the chick as it develops in forming protoplasm for its own body. People who are on the verge of collapse through starvation can be given an appropriate mixture of amino-acids. These do not need any digestion and can therefore be used by the body immediately.

Plants and Animals

Throughout this book we are trying to convey an impression of the unity of life and to show you that the same principles hold for all living things. Thus we have insisted that the living substance in all living things is protoplasm, and that protoplasm is very similar in both plant and animal and requires

the same food substances. We shall point out in later chapters that in every case energy is obtained by chemical changes known as respiration and that there are fundamental similarities also in growth and in reproduction.

We have now come to the point, however, where there is a very important distinction to be made clear. While animals have to obtain proteins, carbohydrates and fats "ready-made" by eating solid materials from other living things (or from the dead bodies or waste products of other animals), *the green parts of plants can, with the aid of light, make their own food from the carbon dioxide of the air and water and salts from the soil.*

There are, of course, other quite important differences between plants and animals but they are less significant than this big difference in feeding. Thus animals usually move about to seek their food (a few like corals—Fig. 16—are stationary and "fish" for it with their tentacles) while a plant can best obtain the supplies that it needs by being anchored in the soil and adjusting its parts in order to get the maximum of light and water (p. 188). If an animal is to move about successfully it must be compact but a plant is under no such compulsion: on the contrary, it will absorb its water and salts most efficiently if its roots are richly branched and it can best take in the carbon dioxide and sunlight that it needs if the parts which make its food (usually, but not always, the leaves) are flattened and spread out in the air. Again, an animal which moves needs muscles and will be most successful if it possesses a set of sense organs, nerves and brain to direct its movements as it searches for food.

A Page of History

The discovery of the facts relating to the manufacture of food by plants was a long and tedious process. It was delayed (as was the study of animal physiology) by a lack of knowledge of chemistry and physics—more especially by ignorance of the composition of the air.

The first scientific experiment in plant feeding of which we have any record was carried out in the seventeenth century by van Helmont (1577–1644). He completed his university

study of philosophy at the age of 17 and of theology and medicine when 22! He married a wealthy girl and then practised as a doctor—charging no fees. He made a hobby of the study of plants.

Van Helmont planted weighed willow cuttings in weighed amounts of soil. He watered the cuttings (which rooted and grew) with the purest water that he could get (rain-water) and found that the plants increased greatly in weight though the soil decreased by very little. Even when the plants were dried they still weighed much more than when planted, and the increase was far greater than the decrease in weight shown by the soil. Van Helmont concluded that the extra weight of the plants was due to water that had been built into them. We know to-day that he was only partly right—that the increase is due to carbon dioxide from the air combined with water—but we must remember that van Helmont carried out his experiment before anything was known about the air.

At about the end of the sixteenth century the compound microscope was invented and, with this new tool to help them, Malpighi (in Italy) and Nehemiah Grew (in England) were able to study the anatomy of plants. We have already referred to Hooke's discovery of the cell (p. 28). Any sound ideas as to the working of the plant body, however, could only be put to the proof when chemistry and physics had advanced sufficiently, and so it was not until the latter half of the eighteenth century that much progress could be made.

After the discovery of oxygen by Priestley (1733–1804) and of hydrogen by Cavendish (1731–1810) came the startling observation that, in light, green plants behave differently from animals and actually improve the air. Priestley seems first to have made this observation but it was left to Lavoisier (1743–94), Jan Ingenhousz (1730–99) and de Saussure (1767–1845) to explain Priestley's results.

Lavoisier is best known for his work on oxidation: he "put the chemistry of combustion on the right road". He realised that respiration consists of an exchange of carbon dioxide for oxygen and his results did more than anything else to influence the work on plants described below. As a member of "the old order" he was guillotined in 1794, his release on

the grounds of his service to science being refused with the oft-quoted words—"La République n'a pas besoin de savants".

Ingenhousz, who heard of Priestley's observations on the improvement of "polluted air" by live plants, carried out experiments which proved that the green parts of plants alone are effective in improving air, and that they act thus only in light. He showed that non-green parts of plants behave like animals even when in the light—"polluting" the air—while all parts of plants behave similarly at night.

As a last example we may mention the beautiful work of de Saussure, who demonstrated the quantitative relationships between amount of carbon dioxide and oxygen involved in plant activities. De Saussure also realised the importance of salts in the soil.

The brief summary given above brings out the international character of scientific research—"Science knows no boundaries". Malpighi was born in Italy, Grew, Cavendish and Priestley were British, van Helmont and Ingenhousz were Dutchmen, while de Saussure and Lavoisier were born in France.

PHOTOSYNTHESIS

Photosynthesis (or Carbon Assimilation) is the first and the best known step in the building up, or *synthesis*, of food by the plant. It is the process by which glucose is built up from carbon dioxide and water, and since light (the Greek word for which is "phos") is employed to bring this about, the name photosynthesis is used.

We have already pointed out that we can regard sugars (and starch) as compounds of carbon and water (p. 75): in fact by heating them strongly it is quite easy to break them up into charcoal (which is pure carbon) and steam (which, of course, is water). You will not be surprised to learn, therefore, that glucose in photosynthesis is made from water and the carbon of the carbon dioxide, and that the oxygen of the carbon dioxide is given off as waste. It is thus true to say that a green plant while it is making food (and that happens only in light) takes in carbon dioxide and gives out oxygen but it would *not* be true to say that plants "breathe in" carbon dioxide and

A

B

Fig. 54. Green plants need light.

A. The fern seen here is growing in the light of a powerful electric flood-lamp, deep in the caves of the Cheddar Gorge, Somerset. The remainder of the caves are quite bare of plant life.

[Photo: Gough's Caves, Cheddar.]

B. Under the yew trees of Kingley Vale, Sussex. The ground beneath the trees is practically bare of plant life and it was previously thought that this was due solely to the fact that very little light passes through the thick foliage. It is now known that the main factor is the extreme efficiency of the yew roots in removing water from the soil. [Photo: R.D.G.]

"breathe out" oxygen, for this process of photosynthesis has nothing to do with respiration. It is, in fact, the reverse of respiration.

Now this means that the carbon and the oxygen of the carbon dioxide have to be separated from one another and this is so difficult a process that a large amount of energy is needed to perform the task. You may know that although carbon dioxide contains a far larger proportion of oxygen than air does (73 per cent. as against 20 per cent.) magnesium is about the only common thing that can burn in it since it is about the only thing which, in burning, has the energy necessary to "tear out" the oxygen from the carbon dioxide.

In photosynthesis, energy is needed to the same degree to tear out the oxygen from the carbon dioxide and then to make the carbon combine with the hydrogen and oxygen of the water and so form glucose. Energy cannot be created or destroyed and the leaf which is carrying out photosynthesis cannot make its own energy but must obtain it from outside. Light is the form of energy used and the green substance in leaves—*chlorophyll*—has the power of absorbing some of the energy of sunlight and using it for carrying out the chemical changes involved.

We are now in a position to summarise the whole process in a chemical equation:

$$\text{Carbon dioxide} + \text{Water} + \text{Energy of sunlight} \xrightarrow{(\textit{Chlorophyll})} \text{Sugar} + \text{Oxygen.}$$

We may use chemical formulae if you like (though it is doubtful if they will help us further in understanding the essential points of the process) and so write the equation thus:

$$6CO_2 + 6H_2O + 674 \text{ Calories}^1 \xrightarrow{(\textit{Chlorophyll})} C_6H_{12}O_6 + 6O_2.$$

The 674 Calories is the actual amount of energy needed to make one gram-molecule of glucose (i.e. 180 grams or $6\frac{1}{2}$ oz.) and would, in the form of heat, be sufficient to raise the temperature of about two gallons of water from room temperature to boiling-point.

[1] A Calorie is a unit of energy: see p. 102.

Leaves, the Food Factories of the Plant

These are organs adapted to perform three important functions: to absorb carbon dioxide from the air, to absorb light rays (normally from sunlight, but artificial light may be equally effective: see Fig. 54A), and lastly to use the energy derived from the light to bring about the chemical change between the carbon dioxide and water.

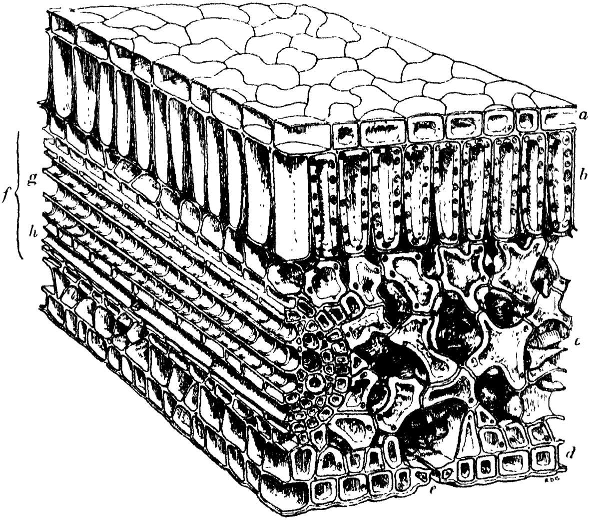


Fig. 55. Diagram of a small part of a leaf. *a*, upper *epidermis* (skin); *d*, lower *epidermis*, with *stoma* (*e*); *b*, "palisade" cells and *c*, spongy tissue—both containing *chloroplasts*; *f*, a vein, consisting principally of cells for the conduction of water (*g*) and food (*h*).

The absorption of light demands a large surface, and so it is an advantage that the leaves of practically all plants are thin flat structures, spread out so that they catch the light. The actual absorption is carried out by the chlorophyll which we find in small *chloroplasts* which are almost always oval—those of Spirogyra (p. 25) are exceptional.

The outer skin or *epidermis* of the leaf is rendered water-

proof by a thin, transparent *cuticle*, but there must, of course, be openings in this skin through which gases can pass: these are small but very numerous. We call them *stomata* (Greek *stoma*—a mouth). In a single large leaf there may be several million: an average number is about 200,000 to the square inch! In most leaves they are mainly on the lower side, but in floating leaves—such as those of the water-lily—they may be on the upper surface only. The cells which contain the chloroplasts make up the interior of the leaf. The uppermost layers consist of cells which have many chloroplasts and which look like the stakes of a palisade, while the rest contain few chloroplasts and are arranged in a much looser and more spongy way. Air which comes in through the stomata circulates freely in the air spaces inside the leaf and so the cells responsible for photosynthesis can take in their supplies of carbon dioxide and get rid of their waste oxygen easily.

We have already pointed out (p. 36) that the network of veins in the leaf is important as a supporting skeleton and we shall describe later (p. 134) the way in which they transport both the raw materials and the manufactured food.

If leaves are to do their work properly, it is of course essential that they should be so arranged that they obtain an adequate amount of sunlight. It is interesting to notice how different plants achieve this. Leaves on a branch of a tree, for example, often form a *mosaic* in which no one leaf shades another. Plants with weak stems climb by various means so that their leaves literally "get a place in the sun". Yet other plants have practically no stem at all but bear a *rosette* of leaves which lie more or less flat on the soil: the common daisy and dandelion are examples of this. Finally, the leaf-stalks of many plants are capable of adjusting themselves, day by day and even hour by hour, so that the leaf-blades are always at right angles to the light which falls on them.

Other Syntheses in Plants

We have insisted that the main food materials needed by all living things are sugars, proteins (and fats) and we have now shown how glucose is made in the green plant. The sugar which is formed as a result of photosynthesis is frequently

more than is needed at the time and it is then stored up in the leaves or other parts of the plant until it is required. It may be stored as cane-sugar (e.g. in sugar cane or sugar beet) or as starch. Starch is not soluble and may often be seen in leaves, bulbs, tubers and other parts of the plant in the form of neat little grains, which show up as dark blue or black specks when treated with iodine solution and viewed under the microscope. Sugars on the other hand are soluble and so can travel about the plant dissolved in the sap which moves through the veins. During the day sugar is usually formed in the leaves more rapidly than it can be carried away and until evening it is stored up in the cells of the leaf as starch, only to be reconverted to sugar and removed (*translocated*) during the night. This change from sugar to starch and *vice versa* is apparently a quite simple chemical change and is carried out by enzymes,

$$xC_6H_{12}O_6 \rightleftharpoons (C_6H_{10}O_5)_x + xH_2O.$$

(Although we call this a simple change it is so difficult for man that only the breaking-down and not the synthesis has been accomplished so far.)

Plants can make their own amino-acids (for the making of proteins) as well as glucose. *This process can be carried out only by plants and is just as important as photosynthesis*, but we know little or nothing about the details beyond the fact that salts containing nitrogen are needed. These are taken in as nitrates or as compounds of ammonia (e.g. "sulphate of ammonia"). Fats are also made by plants and almost certainly from sugars. We know that part of the fat molecule (*glycerol* or *glycerine*) is really a carbohydrate, while the rest of the molecule, made up of *fatty acids*, is also very probably of sugar origin.

Thus, the plant actually makes for itself practically all the food that it needs for growth and energy. New protoplasm is made from the proteins (which are formed from the amino-acids) and small amounts of fats, sulphates, phosphates and salts of calcium, potassium, iron, etc. The cell walls which are so important a part of the plant body are made from cellulose, a substance which is chemically very similar to starch,

and which is made with equal ease (again, by plants only!) from sugar.

A large number of other things are formed to a lesser extent by various plants: we may mention as a few examples rubber from the milky juice of the rubber tree, the tannin which is so important for the treatment of skins in the manufacture of leather, the caffeine which makes our tea and coffee so efficient as a stimulant, quinine and countless other drugs and even some, at least, of the vitamins of which we hear so much today. We cannot here go into details of the fascinating story of plant products—you may read something of it in an extremely interesting book called *Cargoes and Harvests* by Peattie.

Salts and the Plant

We are all familiar with the fact that plants take *water* from the soil but it is not so obvious (yet equally true) that they also absorb *inorganic salts*. The farmer, of course, manures his fields, or adds artificial fertilisers, to replace the salts removed by crop plants. It can be shown by chemical analysis that all plants contain certain salts, e.g. sulphates, chlorides, phosphates, carbonates, salts of iron, etc. These are taken in *in solution in water* and, by growing plants in water containing selected mixtures of salts, it may be shown that generally speaking *all* plants require about the same mixture for healthy growth. We cannot here discuss the rôles of all the salts required but mention may be made of some of the elements whose absence is most disastrous. In the absence of compounds of iron or of magnesium, for example, no chlorophyll is formed and the plant is a sickly yellow. Without nitrogen salts the manufacture of protein is impossible and the plant finally dies. Calcium salts appear to be necessary for cell-wall formation, while phosphates are needed for sugar manufacture. (It is important to remind you that phosphate is not a *part* of the sugar itself—but it is a part of the *machine* for the manufacture of carbohydrates.) It is interesting to note that extremely minute amounts of some substances have astonishing effects. Thus boron is needed for growth—but one part in a million in the water absorbed by

the plant may be sufficient. It is sometimes completely absent from soils and must be added in such cases or certain diseases arise in crop plants (p. 263). Much of the research work in agricultural colleges is devoted to a study of such things—with the aim of producing "bigger and better" vegetables, cereals and fruits.

Fig. 56. "Water-culture" experiments. The left-hand pot contains a solution providing salts containing calcium (Ca), potassium (K), nitrogen (N), phosphorus (P), magnesium (Mg) and iron (Fe). Each of the other pots lacks one of the elements as indicated. [Photo: Prof. J. G. Coulson.]

PRACTICAL WORK

1. Potatoes or Autumn Crocus corms grow in their season without being given water or additional food: weigh such a specimen at intervals (a letter balance will serve) and find whether its growth involves increase in weight.

2. Examine plants which have organs specialised for food storage. Notice also the layers of stored fat in carcases hanging in butchers' shops.

3. *Tests of food materials.*

(*a*) Carbohydrate. To the solution to be tested add 2 or 3 drops of a 1 per cent. solution of α-naphthol in alcohol. *Cool* and add conc. sul-

phuric acid carefully to form a lower layer. Rotate gently: a violet ring at the junction of the liquids indicates the presence of carbohydrates. Use any "solution" of starch or sugar. Starch can also be identified by testing with iodine which turns it black: glucose and certain other sugars (but not cane-sugar) give a red precipitate when boiled with Fehling's solution.

(*b*) Fats, when melted, give a "grease-spot" on white or brown paper. Test a brazil nut by rubbing the cut surface on warmed paper.

(*c*) Protein. Add Milton's reagent to the liquid to be tested (e.g. uncooked white of egg or crushed peas mixed with water). A curdy white precipitate, which turns brick-red on heating, indicates the presence of protein.

Use these tests on food-storage organs of plants and on materials used for human food.

4. To show that the materials of living things contain carbon compounds, heat plant or animal substances gently until all water has been driven off and then heat to redness for a minute or two: notice the residue of carbon. If the heating is continued, the carbon is oxidised and only ash (i.e. salts) remains.

5. To show that nitrogen is present in living materials and especially in proteins, heat dried specimens (e.g. crushed peas) with soda-lime. Note the evolution of ammonia (test with red litmus)—this of course is a compound of nitrogen and hydrogen.

6. That carbon and water are combined in carbohydrates—starch, cotton-wool (cellulose), sugars—can be demonstrated by heating them strongly until no further gases are evolved.

7. Most of the sugar formed during a period of rapid photosynthesis (e.g. on a sunny day) is converted to starch until it can be removed at night. Leaves to be tested for starch should be taken from the plant in the second half of a sunny day and the chlorophyll removed by plunging them into boiling water for a minute and then soaking them in cold alcohol for a few days (or for a few minutes in boiling alcohol with adequate precautions). Finally soften the leaves with hot water and put them in dilute iodine solution. Young geranium or fuchsia plants are very suitable.

Leaves for testing may be prepared as follows:

(*a*) Leaves from a plant kept in the dark should be compared with leaves from a plant kept in sunlight.

(*b*) Part of a leaf may be covered with tinfoil held by strips of glass.

(*c*) One leaf of a plant may be enclosed in a flask (see Fig. 57 B) containing caustic soda solution, the neck being plugged with cotton-wool (this will keep the air in the flask free of carbon dioxide).

(*d*) A variegated leaf: make a drawing to show the distribution of chlorophyll before decolorising it and compare it with the distribution of starch.

(Except for (*d*) the plant used for the experiment should be kept in the dark for at least the previous 24 hours.)

8. The evolution of oxygen by an aquatic plant (e.g. *Elodea*) during

photosynthesis can be demonstrated by the apparatus shown in Fig. 57 A. If there is no carbon dioxide in the water, no oxygen will be evolved: this can be shown by using water recently boiled to expel dissolved gases and cooled out of contact with air. On the other hand a good supply of carbon dioxide can be assured by blowing expired air through the water or adding a little—about 0·1 per cent.—sodium bicarbonate. Even then, it can be shown that the experiment will not work in the dark—why?

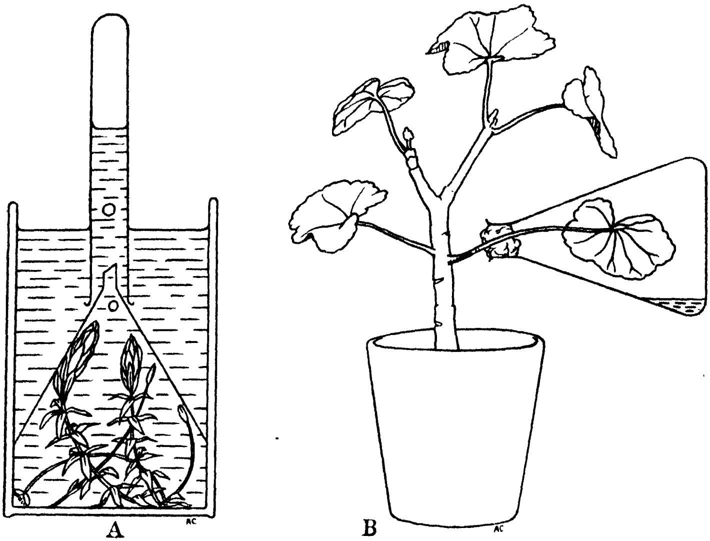


Fig. 57. Experiments on photosynthesis. Clamps omitted in each case. (See Practical Work, §§ 8 and 7*c*.)

9. Another experiment by which the absorption of carbon dioxide and the evolution of oxygen can be shown is as follows. Place some healthy green shoots—e.g. willow—in a stoppered bell-jar over water and allow a lighted taper to use up all the oxygen it can in the bell-jar. Expose the experiment to bright sunlight for a day or two and then test again with a lighted paper. Repeat (*a*) with the bell-jar in darkness instead of sunlight and (*b*) with leaves killed by immersion in hot water.

10. That leaves can form starch from sugar can be shown as follows. Sterilise two beakers with formalin, rinse them out with boiling water and half fill one with 3 per cent. glucose solution and the other with distilled water, both liquids having been sterilised by boiling. Take two leaves

from a geranium plant which has been kept in darkness until its leaves have lost all their starch, cut the stalks off close to the blades and float one in each beaker. Cover the beakers and put the experiment aside in the dark for a week and then test the leaves for starch. (The sterilisation is necessary to prevent bacteria, etc., from multiplying in the sugar solution.)

11. Examine sections of leaves under the microscope. Chloroplasts may be seen in a moss leaf: if the leaf has been recently exposed to light, starch grains inside the chloroplasts may be shown by treatment with iodine.

12. Stomata can be seen (under the microscope) on a leaf such as pine, if it is examined by reflected light, or in a piece of epidermis stripped from a thick leaf such as bean or narcissus and examined by transmitted light.

13. A solution of chlorophyll may be obtained by steeping grass cuttings in 80 per cent. acetone.

14. Notice the way in which different plants spread out their leaves in the sunlight. Look for examples of rosette plants and leaf mosaics on a tree and study the different methods by which weak-stemmed plants climb. (See also Chapter XII: Practical Work, § 4.)

15. Taste a really green banana and test it for starch. Ripen similar bananas, repeating your tests at intervals, and find out what happens to the stored starch. Similar experiments can be carried out on developing potatoes, lily and hyacinth bulbs, etc.

16. Strip the lower epidermis from a holly leaf, invert the remainder on a microscope slide and examine the spongy tissue by reflected light.

CHAPTER VI

THE FEEDING OF ANIMALS

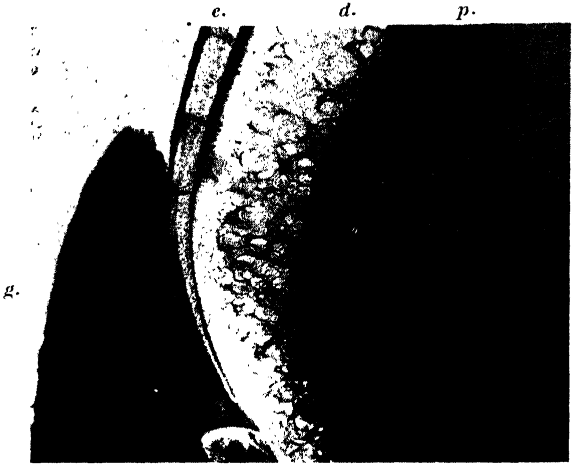
We have already discussed the food requirements of living things. Like plants, animals require proteins for body-building,[1] carbohydrates (and fats, if available) as sources of energy and also quantities of water and salts: in addition, they need certain substances called vitamins. An animal differs from a plant in that it obtains its food from other animals or plants—it eats—but whatever it feeds upon, the chemical substances it obtains are those we have just mentioned.

Since the proteins of different plants and animals contain different mixtures of amino-acids (p. 75), all proteins are not of equal value to us. Only cannibals get exactly the right proportions of amino-acids for making the proteins their bodies require! The next best sources are lean meats of various kinds, fish, milk, cheese and eggs. Strictly vegetarians rely on the proteins found in nuts, peas and beans. These do not contain such a suitable mixture of amino-acids as do meat foods but this is not a serious matter if rather larger quantities are eaten.

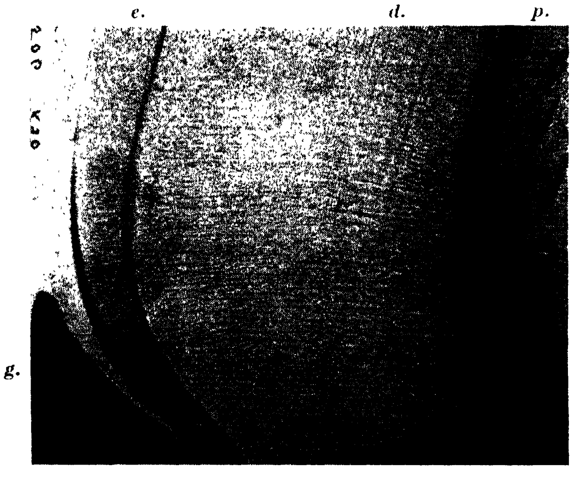
Sugar and starch (found in potatoes, in anything made from flour, and in all cereals) together with fats and oils (e.g. butter, fat meat, olive oil) are our main sources of energy. Animal and vegetable oils are in the same class of chemical compounds as fats: in fact, the fat in margarine is made from vegetable oils quite easily by combining them with a small proportion of extra hydrogen. Weight for weight, fats yield far more energy than carbohydrates or proteins, as can be seen from a study of the figures in the table on page 104. Animal fats are also important as the only sources of vitamin D.

Surprisingly large quantities of water are found in most of our foods, especially in fruit and green vegetables. On the

[1] In warm-blooded animals, proteins appear also to play an important part in helping to regulate the body temperature.



(*a*)



(*b*)

Fig. 58. Vitamin D and development of teeth. (*a*) Section of a tooth from a puppy fed on diet deficient in Vitamin D. (*b*) Section of a normal puppy's tooth: notice the much firmer enamel and dentine.

g. gum. *e.* enamel. *d.* dentine. *p.* pulp.

[By courtesy of Lady Mellanby and the *British Dental Journal.*]

other hand, seeds such as peas, beans and nuts contain very little and so may be regarded as very concentrated foods (see table on p. 104).

Vitamins are present only in very minute quantities in our food, but are essential for maintaining good health and proper development. It was due to the absence of one of these—vitamin C, which is found in fresh fruit and vegetables —from the diet of sailors in bygone days that scurvy became such a curse. In recent times lack of vitamin D has been shown to be the cause of rickets, a disease in which the bones of a baby fail to harden and the teeth to develop properly. Since vitamin D appears to be formed within the body by exposing the skin to sunlight, it is not surprising to find that poor teeth and rickets are found mainly in the slums. Rickets can be cured by exposing the body to light or by taking oil from the liver of cod or halibut. Vitamin A is important, among other things, for maintaining the efficiency of the eyes, especially at night: during the recent war, night-fighter pilots were given extra vitamin A to improve their night vision.

That vitamins have an important bearing on health in general, apart from preventing certain diseases, is shown by experiments carried out by Lever Bros. at their factory at Port Sunlight.[1] In one experiment, carried out through the whole of one winter, a group of about 300 of the staff received extra amounts of vitamins A and D, in the form of capsules. A careful record was kept of the absences due to illness among the members of this group and this record was carefully compared with that of a similar group of 300 who did not receive any extra vitamins. The results, which speak for themselves, can be tabulated as follows:

	No. of absences per 100 persons	Hours of work lost per 100 persons
Group I (extra vitamins)	53·5	1555
Group II (no extra vitamins)	70·5	2397

As you will see from the table on the next page, vitamins are found mainly in fresh fruit and vegetables, wholemeal bread

[1] As a result of these and similar experiments, foods rich in vitamins are often known as *protective foods*.

Details concerning the chief vitamins

Vitamin	Function	Food in which it is found	Effect of cooking
A	Specially necessary for healthy growth. Builds up resistance to infection and improves night vision	Animal fats[1] and oils. e.g. milk, butter, cod liver oil, egg-yolk, liver. Green leaves, e.g. lettuce. Some fresh fruits and vegetables	Destroyed by prolonged cooking or by cooking in air, i.e. frying
B_1	Absence causes disease known as beriberi (a disease of nerves and digestion). Plays important part in growth	Yeast and yeast extracts (e.g. marmite). Whole cereals—therefore in wholemeal (not white) bread and in unpolished (brown) rice. Egg-yolk, liver, heart, kidney, potato	Destroyed in canning and largely removed in the milling of cereals
B_2 complex	Absence causes pellagra (a disease of skin and food canal)	Yeast and yeast extracts (e.g. marmite). Liver, lean meat, fish, milk, egg-yolk, tomatoes	Not affected by cooking or preservation
C	Absence causes scurvy. Builds up resistance to infection	Oranges, lemons and grape-fruit. *Germinating* seeds, such as peas, beans and cereals. Tomato, swede, potato	Most sensitive of all the vitamins: destroyed by salting, drying, prolonged cooking, etc.
D	Required for hardening of bones and teeth. Absence causes rickets	Animal fats[1] and oils. (Also formed under skin by action of sunlight)	Destroyed only by very prolonged cooking
E	Plays an important part in successful reproduction	Whole cereals and lettuce	—

[1] Except pork and bacon fat, and lard.

and animal fats, including milk. For growing children, milk in particular is a very important food: experiments have shown that an extra pint a day makes a surprising difference to the health, vigour and rate of growth of most boys and girls.

Salts are present in many of the foods we eat and it is probably true to say that most of us probably get adequate quantities of them. This statement must, however, be qualified in certain directions. First, the valuable salts in cabbage and other greens are dissolved out by prolonged boiling, and wasted. Again, in some districts deficiencies of one or more of the necessary salts may occur: there are, for example, parts of England and Switzerland where people do not get enough iodine in their diet (normally it is present in small quantities in water and in common salt) to allow their thyroid glands (p. 205) to work properly.[1]

Finally, there is reason to suppose that gradual exhaustion of the natural salts in the soils of many food-producing areas in the world (p. 129) is giving rise to serious deficiencies in the salt-content of certain of our foods—and recent research suggests that adequate amounts of salts in the food we eat are as important for the full health and normal functioning of the body as adequate quantities of vitamins are. In many cases, at least, the salt-content of plants can vary considerably without the plants appearing to be different in any way. Thus, the calcium content in healthy lettuce leaves can vary two-fold and in spinach leaves three-fold according to the calcium content of the soils in which they are grown.

Animals, including man, are however affected by the amounts of salts in the foods they eat. In one experiment, lambs fed on hay which was rich in salts because it had been grown on well-fertilised soil gained three times as much weight over a given period as other lambs from the same flock growing up under identical conditions but fed on hay grown on mineral-deficient[2] soil and therefore with a low salt-content. In another experiment, it was found that male rabbits fed on

[1] Comparable diseases are found in plants (p. 263).

[2] The salts in soils and plants are commonly spoken of as the mineral content.

mineral-deficient hay lost all their reproductive powers—but regained them when put back on to a mineral-rich diet.

Other experiments, again, have shown that the vitamin C content of tomatoes can be tripled by the addition of a pinch of manganese salts to the soil in which the tomato plants are growing, if that soil is deficient in manganese; and that the iron content of milk can be more than doubled by proper treatment of the soil of the fields in which the cows graze—results which are obviously important in connection with human health.

If you study the table of food analyses on page 104, you will realise that we "eat" large quantities of *water* but we need to supplement this by drinking a fair amount also. Most of us probably drink far too little: an average person needs to drink *at least* 3 or 4 pints of fluid daily. A sufficient supply of water is needed to make certain that all the food which is digested is dissolved and then absorbed into the blood (p. 98)—if this does not happen it is simply wasted. In addition, large quantities of water are needed for getting rid of the waste products from the body (p. 166) and the more we drink the more thoroughly we flush out those undesirable and often somewhat poisonous waste products.

The *roughage* mentioned in our table is contained in plant foods and consists of cellulose (p. 25) and woody threads such as the stringy veins seen in celery. These are not digested at all but they are nevertheless quite important since they gently massage the inside of the intestines as they pass through and so help to keep them fit for their work.

Digestion

Food as eaten is not immediately ready for use by the various parts of the body nor, since practically all of it is insoluble, could it be absorbed into the blood. It needs, therefore, to undergo the process of digestion during which its various components are converted into substances which are soluble, e.g. insoluble starch is transformed to sugar, and proteins are broken down to amino-acids.

Digestion is carried on in the food canal by the various digestive juices. The saliva in the mouth, for example, can

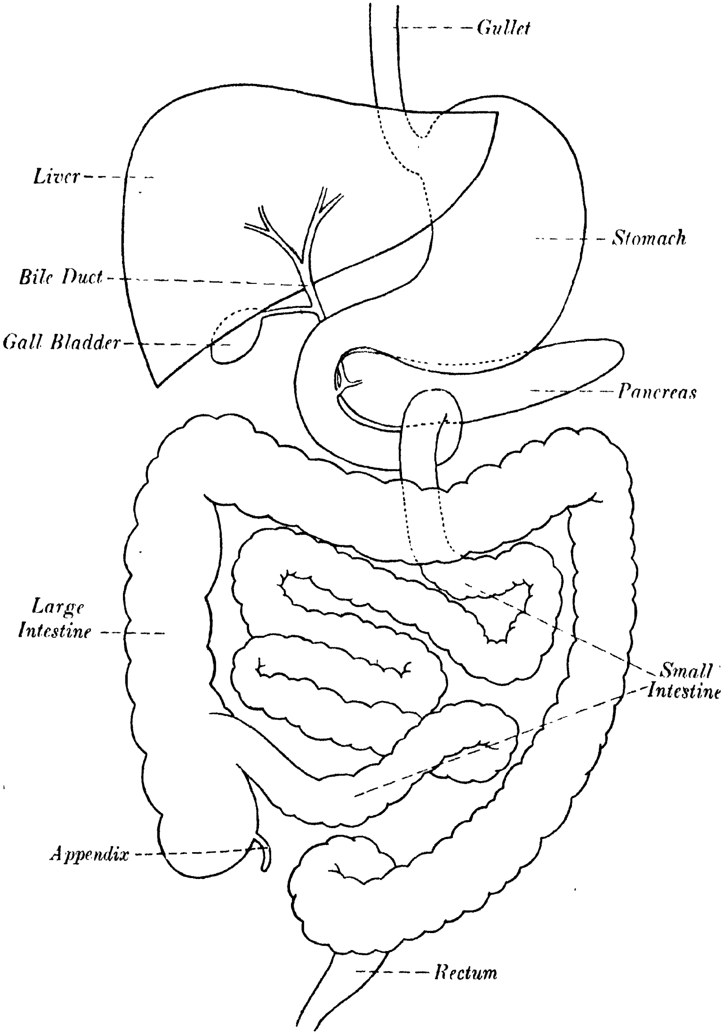


Fig. 59. The human food canal (mouth and throat omitted).

digest starch by changing it to sugar. This is a chemical change for which the saliva—or rather a special chemical called *ptyalin* found in it—acts as a catalyst. (You will have met catalysts before if you have used manganese dioxide to "help" the chemical change by which oxygen is obtained from potassium chlorate. Catalysts such as ptyalin which are made by, and used in, living organisms are called *enzymes*.)

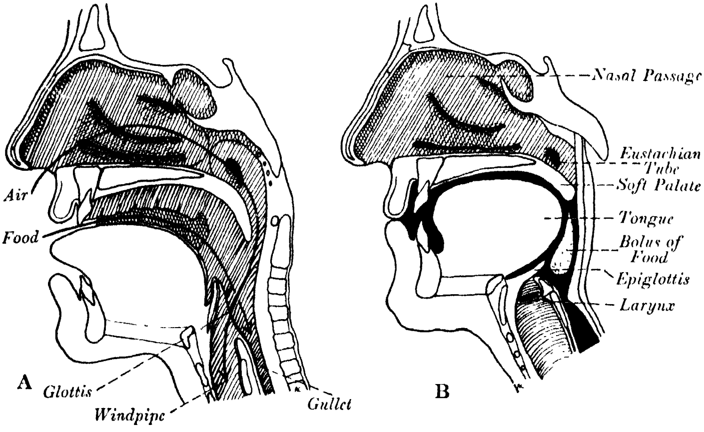


Fig. 60. The mouth and nasal cavity. A, Paths of air and food. B, The act of swallowing. Note how the food "bolus" is pressed back by the tongue, and the air passages are closed by the soft palate above and the epiglottis below. [After Keith.]

Digestion, then, begins in the mouth, but the thorough pulping of the food which should result from chewing is much the most important thing which takes place there. Without it, the digestive juices of the stomach and intestines are unable to mix properly with the food and so are unable to do their work. Most people think that the stomach is the most important part of the food canal for digestion. It is true that it carries out some digestion, but its main function appears to be to store the whole of a meal (and it is often grossly overworked in this respect!) and thus to act as a kind of hopper

from which the food is passed on, a very little at a time, into the small intestine where most of the digestion takes place.

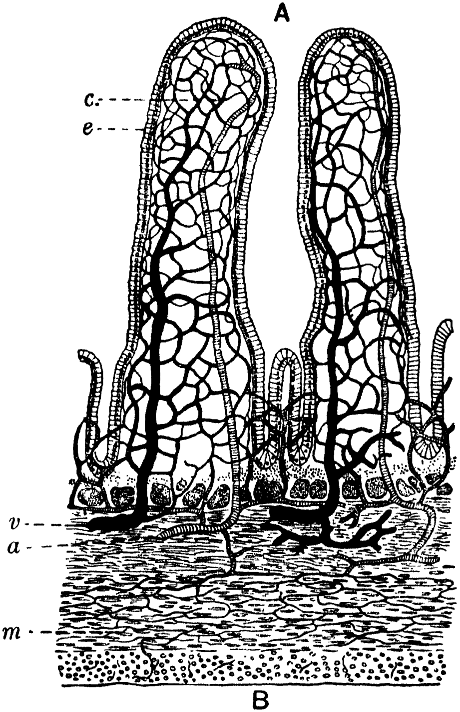


Fig. 61. Section of a piece of the wall of the small intestine. A, Cavity of intestine. B, Part of coelom wall. *c*, Capillaries of a *villus*, connected with an artery (*a*) and a vein (*v*). The apparently empty space in the villus is really filled with lymph which is drained away through lymph vessels (not shown); and between the villi are the glands which secrete the intestinal juice. *m* are the muscles which cause peristaltic movement. [From Fox: *Biology*.]

The gastric juice of the stomach takes some while to soak completely into a meal and until it does so the ptyalin continues to digest the starch. Ptyalin, however, can only work

while it is kept alkaline and so stops when the gastric juice reaches it, for the latter contains hydrochloric acid, the main function of which is to kill bacteria taken in with the food. In addition to hydrochloric acid, the gastric juice contains *pepsin*, an enzyme which digests proteins to give substances called *peptones* (which may be regarded as half-digested proteins). Fats are also melted by the mere warmth of the body.

Once within the small intestine all digestible substances in the food—carbohydrates, fats and the peptones derived from the proteins—are digested by the enzymes in the various juices present. The chief of these juices is certainly the pancreatic juice made by the pancreas and this is helped by the intestinal juice made by the walls of the intestines themselves and also, to a slight extent, by the bile which comes down from the liver.

As the food is digested, particularly in the small intestine, the substances formed dissolve in the water present (provided, of course, that there is enough water there), and once in solution they can be absorbed. The sugars and amino-acids which are produced by the digestion of carbohydrates and proteins respectively are absorbed by the blood which is flowing in the capillaries lining the walls of the small intestine.[1] The extent to which this absorption is carried on will depend on the extent to which the digested food comes into contact with the walls, and we find that the walls of the small intestine bear large numbers of small finger-like projections or *villi*. These are continually moving to and fro in the digested and digesting food and so aid absorption.

So well do they do their work in fact, that by the time food

[1] Very little is known with certainty about the digestion and absorption of fats. In the past, it has usually been stated that fats are digested in the small intestine, absorbed into the lymph (Fig. 61 and p. 132) and not into the blood and that the fats are immediately reconstituted in the lymph. Scientists today are by no means convinced that such digestion takes place: it is possible that part, if not the whole, of the fats pass through the intestine walls without change Some of the fat is found as milky droplets in the lymph vessels of the small intestine (for which reason these lymph vessels are called *lacteals*), but some of the fat is also found in the blood in the intestine veins.

leaves the small intestine about 95 per cent. of the digestible food has been absorbed. During the passage through the large intestine the greater part of the residual water is absorbed and the partially dried remains—the *faeces*—are passed out of the body at the anus. This part of the food canal is a perfect paradise for bacteria, which feed on the undigested remains and multiply.

To such an extent does this take place that the faeces may contain as much as 50 per cent. of dead and living bacteria:

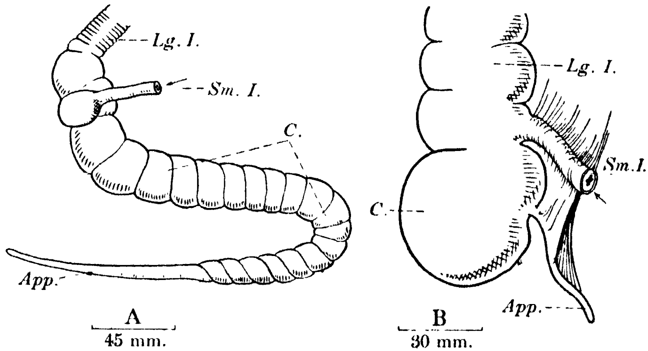


Fig. 62. Caecum and Appendix in (A) Rabbit, and (B) Man. Sm. I., and Lg. I.: small and large intestine, respectively. (In B, the connective tissue holding the appendix is shown.)

the remainder includes excreted salts (p. 172) and dead cells from the intestine walls as well as undigested food. Unfortunately for us, the bacteria not merely absorb the food but make from it substances which are poisonous to us and these poisons are inevitably absorbed into the blood by the walls of the intestines.

In human beings the caecum and appendix are a small useless remnant of what in some animals is, and presumably in our pre-human ancestors was, an important organ. The animals in which we find this part well developed are the mammals which eat plants for their food (*herbivores*). Much of the solid matter in plants is cellulose (p. 25) and no mammal has an enzyme

in any of its digestive juices which can digest it. It can, however, be accumulated in the caecum and appendix and digested there by the action of bacteria. Mammals which

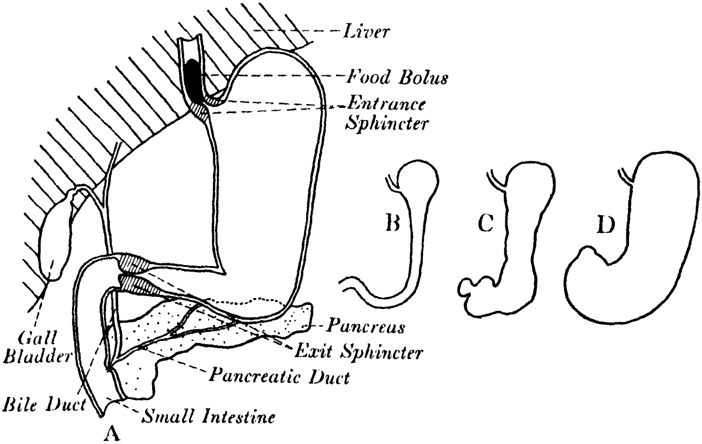


Fig. 63. The Stomach. A, Opened to show sphincters, etc. B, C, D, The outline, from X-ray plates, of the stomach empty, fairly full, and very full. Note the peristaltic waves in C.

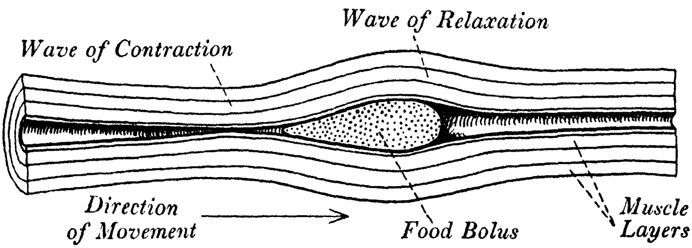


Fig. 64. Diagram of part of the gullet, to show peristalsis.

depend on plant foods cannot afford to waste cellulose: to us, for whom it is a very small item in the diet, such bacterial digestion is not necessary.

You must not think of the various parts of the food canal

as being motionless tubes, doing nothing more than preparing digestive juices and absorbing the products of digestion. They are continually moving: waves of contraction are constantly passing along the gullet and small intestine in such a way that the food is swallowed and gradually forced along in the proper direction. These waves of muscle movement, known as *peristalsis*, are found in the stomach also and here they serve to

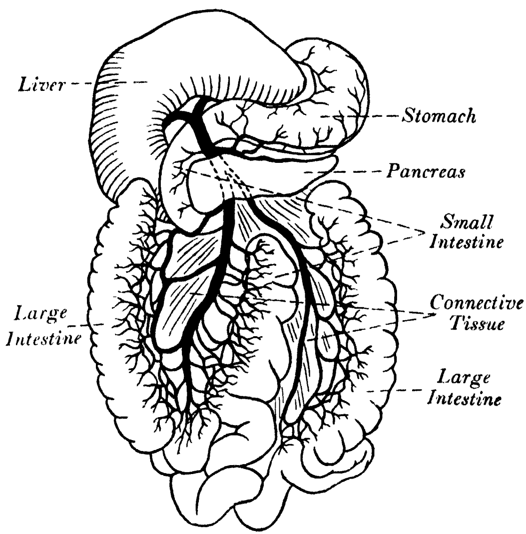


Fig. 65. The course of the "Hepatic Portal Vein" which carries the blood containing the digested food from the stomach and intestines to the liver.

mix the gastric juices with the food and so have an important function in aiding digestion. This gives us a very good example of the influence of the mind on the body. As long ago as 1896 when X-rays had only just been discovered, Cannon at Harvard University used them to watch the movements of a cat's stomach. When the cat was made angry the movements ceased but when the cat was soothed and made to purr the movements recommenced and were even more vigorous than usual!

In ourselves, the movements of the stomach and intestine are influenced, in much the same way, by our moods. Thus it is essential that we should enjoy our food, and give ourselves adequate time for meals. A person who dislikes the food he is eating or is annoyed or eats too hurriedly subjects his digestive organs to unnecessarily heavy strains.

The Liver

This is a most important organ since it is the main storehouse and chemistry laboratory of the body. The digested food in the blood is carried direct to the liver before it is taken to any other part of the body; but the lymph containing part of the fats is emptied direct into the blood-vessels near the heart and so does not go to the liver. If the liver receives more sugar than is required the excess can be converted to glycogen (p. 66) and stored until required, while amino-acids not required for body building can be converted to sugar (and a substance called urea) and used as energy food. In addition, the liver deals as far as possible with the poisonous substances which may be absorbed as a result of bacterial action in the large intestine. Its secretion, the bile, is composed mainly of waste matter but plays, as we have already pointed out, a small part in digestion.

Diet

To be adequate, a person's diet must first of all furnish sufficient protein for the body's growth and maintenance and must also be capable of releasing sufficient energy for all the body's activities.

The most convenient measure of energy is the *Calorie*— the amount of heat required to raise the temperature of a litre of water by one degree Centigrade. (A *calorie*, with a small *c*, is only a thousandth part of this.) Experiments have proved that the energy used by a healthy man's body at rest is remarkably constant: when lying down the body uses about 65 Calories per hour and when resting in a sitting position, about 100 Calories per hour. With increased activity, the amount of energy used increases. Thus the energy used in

ordinary walking is about 170 Calories per hour while in very vigorous exercise it may be anything up to 600 Calories per hour.[1]

By finding out what periods per day a man spends lying down, sitting and in exercise of various kinds, it is possible to calculate his daily energy requirements. Thus for an average man with a sedentary occupation in a temperate climate, the

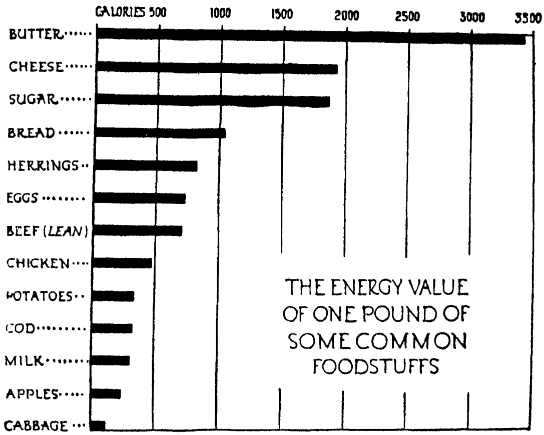


Fig. 66. Diagram illustrating the energy value per pound of some common foods (edible portion only). [From Callow: *Food and Health.*]

figure usually accepted is about 3000 Calories per day: in a cold climate or in very cold weather, more energy will be used in keeping up the body temperature, while in hot climates or in hot weather less energy is required. Again, men doing strenuous work require more energy while women apparently require less than men doing the same work: about four-fifths is the usually accepted ratio.

Experiments on the energy obtained by the oxidation of food in respiration have shown that proteins and carbohydrates yield 4·1 Calories per gram and fats about 9·3

[1] Compare the figures given on p. 160 for the consumption of oxygen.

Analyses and energy values of foods

	Percentage composition*						Calories per lb.
	Protein	Carbo-hydrate	Fat	Salts	Rough-age	Water	
Foods eaten as sources of protein:							
Meat, e.g. (i) beef steak	22	—	7	1	—	70	710
(ii) shoulder of lamb	18	—	28	1	—	53	1510
Fish, e.g. (i) cod	18	—	—	1	—	80	340
(ii) herring	19	—	11	3	—	67	810
Eggs (average weight 2 oz.)	12	—	12	1	—	74	730
Cheese, e.g. Cheddar	25	—	33	4	—	34	1850
Nuts, e.g. almonds	24	12	53	3	3	4	2900
Other foods eaten as sources of energy:							
Brown bread	7·5	46	—	2	2	42	990
White bread	6	49	—	2	—	43	1020
White flour	11	76	1	1	—	10	1640
New potatoes (boiled)	1	20	—	1	1	77	390
Dried peas and beans (average)	19	61	—	3	3	12	1500
Rolled oats	13	69	6	2	1	9	1770
Rice	7	80	1	1	—	11	1640
Butter	—	—	82	2	—	15	3440
Dried fruits, e.g. dates	2	70	—	2	2	23	1330
Honey	0·4	72	—	0·4	—	27	1300
Other foods (eaten as sources of vitamins and salts):							
Milk (1 lb. = ¾ pint)	3	5	4	1	—	87	300
Apples	0·4	10	—	0·4	1	85	190
Oranges	1	9	—	0·5	0·4	88	185
Lettuce	1	2	—	1	1	95	50
Cucumber	0·6	2	—	0·4	0·2	96	40

* Edible portion only.

Calories per gram, figures which are equivalent to about 1850 and 4200 Calories per pound respectively. We can therefore calculate the daily amounts of food we require.

Carnivorous animals can obtain all their energy from proteins but, apart from the fact that protein-foods are far more expensive than foods containing mainly carbohydrates and fats, the human body works best on a "mixed" diet. Some of the food taken must include proteins, but because of their cost and their comparative indigestibility it is not desirable to eat them in excess. It is generally agreed that the amount of protein necessary is about 100 gm. ($3\frac{1}{2}$ oz.) per day for a 3000 Calorie diet and of this amount 30 gm. (1 oz.) should be of animal origin, i.e. from meat, fish, eggs, etc. Growing children require relatively more than adults.

This amount of protein yields about 400 Calories; the remainder must be furnished by carbohydrates and fats. Eskimos appear to live mainly on fat but most of us prefer to make carbohydrates the main source of energy and to eat relatively small quantities of fat.

In addition to these three constituents, the diet should include adequate amounts of water, salts and vitamins. We have already dealt with our need of these.

Diet and Health

Diet appears to play a very important rôle in the maintenance of health and the avoidance of illness. Experiments made by Colonel McCarrison in India on albino rats support this theory. He kept over a thousand rats under the best possible conditions, feeding them on a diet similar to that eaten by certain peoples of northern India, renowned for their fine physique and perfect health. The diet consisted of wholemeal wheat flour, unleavened bread with a little fresh butter, sprouted Bengal *gram* (similar to beans), abundant *fresh* raw carrots and cabbage, unboiled milk, a small weekly ration of raw meat with bones and abundant water for drinking and washing. During a period of two and a half years there were *practically no cases of illness or natural death* (except for a few accidental deaths in the younger generations).

Other groups of rats were kept under identical conditions

but fed on other diets resembling those of Indian races in which certain diseases are prevalent, and the animals became subject to precisely those diseases. A large proportion of human diseases were induced in rats fed on diets disproportionately rich in cereals and poor in animal fats, milk and fresh vegetables. McCarrison adds that of all the faulty diets tried the one which gave the worst results was composed of white bread, unvitaminised margarine, tea, sugar, jam, preserved meat and scanty and over-cooked vegetables—a diet practically devoid of vitamins but one in common use by many people in civilised countries.

Sir John Boyd Orr, now Director-General of the United Nations Food and Agriculture Organisation, once said (and the experiments on rats which we have quoted support the view) that by feeding people, beginning with the mothers and young children, on a diet which is perfect from the point of view of health, we could in fifty years produce a race virile and healthy beyond our dreams. We are not yet certain of all the details of a perfect diet, but we know enough to be certain that we could raise our standard of health by including in our diet more vitamin-containing foods—i.e. fresh fruit and salads, wholemeal (but not white) bread, milk and animal fats (i.e. butter rather than unvitaminised margarine). Civilised diets are also frequently deficient in roughage and many of us do not drink enough water. There is also developing a problem of deficiencies of salts (p. 93).

PRACTICAL WORK

1. Examine the food canal in dissections of rabbit, frog, fish, etc.
2. Examine prepared microscope sections of the stomach wall to see the glands, and of the small intestine to see the villi.
3. Find the percentage of water in various foods (e.g. meat, nuts, bread, fruits) by heating specimens in a steam oven at 100° C. for some hours. Weigh before and after.
4. The movements of the gut in peristalsis can easily be seen under the microscope in *Daphnia* (the water-flea found very commonly in fresh-water ponds) or in blow-fly larvae.
5. (*a*) Chew a small piece of bread for two or three minutes and notice the difference in taste as the saliva digests the starch. (*b*) Add some saliva

to a very dilute freshly prepared starch solution and keep it warm (e.g. in a water-bath about 30° C.). After about half an hour withdraw a drop or two and test with iodine solution for starch. Test the residue for glucose by boiling with Fehling's solution. Repeat the experiment, using commercial diastase.

6. Try the effect of a 2 per cent. solution of commercial pepsin on cubes of cooked white of egg. Add a drop of dilute hydrocholoric acid (and a drop of chloroform to prevent bacterial action) and leave it for a day in a warm place. Repeat the experiment with pancreatic extract (but without the acid).

7. Demonstrate the digestion of oil by the enzyme *lipase*. Remove the hard coat of a castor-oil seed and grind the seed itself with water. Transfer the paste to a test-tube with a little blue litmus, and a grain of camphor to prevent bacterial action. Leave in a warm place for a day or two and note the change in the colour of the litmus owing to the liberation of acids during digestion.

8. Make graphs similar to Fig. 66 for various foods, showing (i) the percentage of protein contained in them, (ii) the cost of protein per ounce, (iii) the cost of the amounts of foods needed to furnish 1000 Calories. Allow for inedible parts.

9. Calculate approximately the amount of protein in, and the energy value of, the food you eat in a day. The table in this chapter may be supplemented by those included in Mrs A. B. Callow's book, *Food and Health*. Allow for inedible parts.

10. Write out a list of the foods you eat in a day and the vitamins they contain; use the table on p. 92 (including the last column of that table).

CHAPTER VII

FOOD: THE INTERDEPENDENCE OF LIVING THINGS

The Importance of Plant Syntheses

It is no exaggeration to say that practically all living things depend for food on the powers of synthesis possessed by green plants. It cannot be too strongly emphasised that, starting from very simple chemical compounds, green plants *make* everything they need in the way of food substances.

As you watch day by day the plants growing in your garden or in the fields, you must try to realise that every new particle of the plant is being built up from food substances made in the leaves. As you watch an apple swell and ripen on the tree, you must picture the adjacent leaves making sugar and the other things necessary and passing them into the fruit. Wherever you see a tree or a whole forest, you must say to yourself that every solid ounce of wood was made from substances manufactured year by year by the leaves. Whenever you see a leaf spread out in the sunlight you should think of it as one of the most important factories in the world—taking in the carbon dioxide and water and salts and using the energy of sunlight to manufacture the food-stuffs which other parts of the plant are using for growth or storage.

Not only are the syntheses carried on by plants necessary to the plants themselves, but they are of the utmost importance to animals as well. We have pointed out that animals, like plants, need proteins, carbohydrates, fats, etc., and that green plants are the *only* things that can make fresh supplies of these substances. Consequently, animals depend directly or indirectly on green plants for their food.

Some of our own foods and the foods of some other animals are actually parts of plants. Thus we eat the green leaves of lettuce and cabbage while large numbers of animals feed almost entirely upon grass. In such foods as potatoes, onions and carrots we are simply eating the foods which green plants

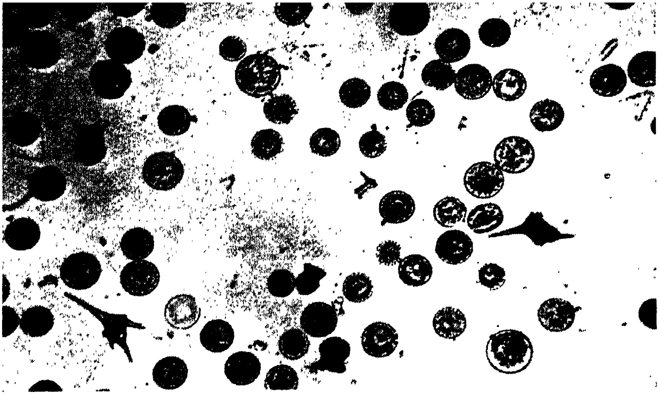
have made and stored up in their underground parts (pp. 220–222). Our flour is made from the food store provided by the wheat plant for the seed (p. 243).

Sheep and cows eat little but grass, clover, etc., and so we cannot but regard mutton and beef as transformed grass, for the amino-acids, fats, sugars and salts of which the grass was made have been rebuilt to form the protoplasm of the sheep or cow. Thus, when we eat mutton or beef, we may say that we are eating "second-hand" grass and clover: the food-stuff in the meat was certainly made in the plants.

The food materials may even be more than second-hand: thus caterpillars eat leaves while small birds eat caterpillars and use this food to form, among other things, the food materials in their eggs. If, then, squirrels eat the eggs or the young birds (as they frequently do) the squirrels are in this case getting their amino-acids at the least "third-hand". You will find that you can make up a large number of what we call *food chains* for human food and the food of animals in this way, tracing the food-stuffs back in each case ultimately to the green plant.

You may be a little puzzled as to what happens in the sea. Here the main source of food supply is not the familiar sea-weed (which is a shore plant) but the incredible numbers of minute floating plants—diatoms and other single-celled organisms—that drift in the open sea. These make their own food as other plants do and so multiply—to such an extent that the surface water of the sea is a perfect "soup" of tiny plants on which small animals feed. These surface waters in fact have been called the "pastures of the sea". The whole collection of small floating forms, plant and animal, is known as *plankton*. The plankton serves as food for larger animals and these in turn are eaten by fish. Thus herrings eat small shrimp-like animals that feed upon plankton: *we* eat the herring.

Since the manufacture of food by the plants of the plankton requires light, it is obvious that they can live and grow only near the surface. Creatures of the deep sea are therefore dependent upon a "rain" of dead plankton and other organisms from the surface waters.



A

B

Fig. 67. *Plankton.* A, Plant plankton—from Lake Winnipeg, Canada (× 100). [Photo: Prof. C. W. Lowe.] B, Plankton animals—Arrow-worms and Crustaceans—from the Atlantic Ocean (× 5). [Photo: R.D.G.] Both plant and animal plankton are found together in *all* oceans, seas and lakes.

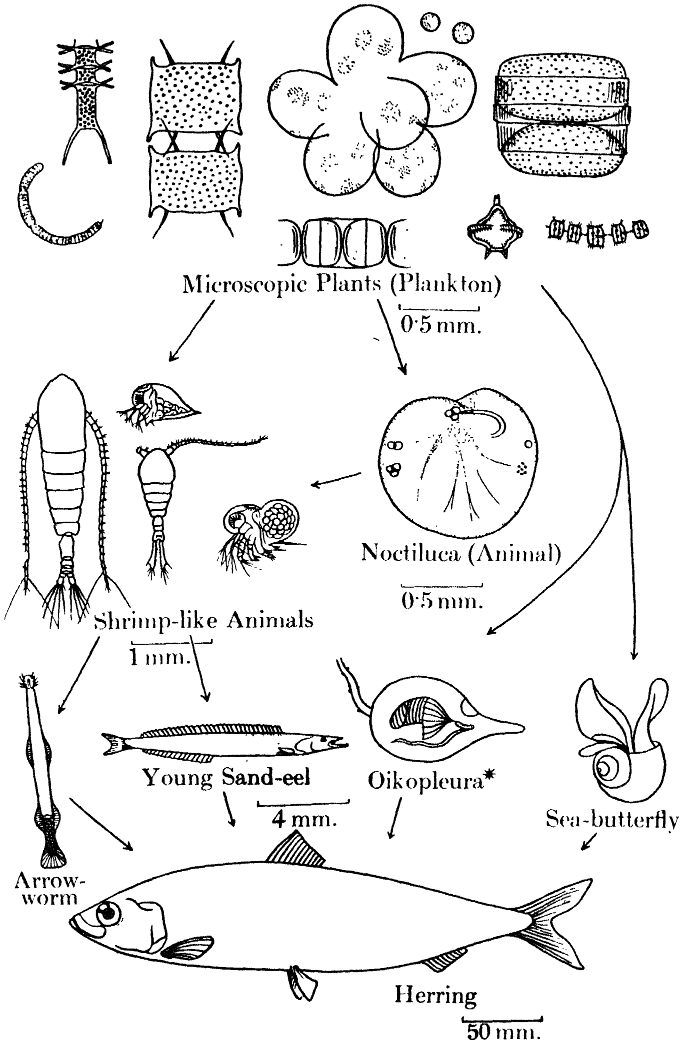


Fig. 68. The food chain of an adult herring. [* *Oikopleura* belongs to the class of animals known as Tunicates or Sea-squirts.]

Energy Chains

We have given examples of food chains but, since the foods are the sources of energy for living things, it follows that the food chains must also be *energy chains*. Whenever we stir hand or foot, we are using part of our food to give us the energy to do the action and the energy we release is exactly the same amount—neither more nor less—as was used in making that quantity of food. We can thus regard our foods as having accumulated energy during their manufacture in the green plant and as being capable of releasing that energy when we require it. Since the energy used in the synthesis of foods in plants is derived from sunlight, we can, from this point of view, regard foods as "bottled sunshine".

Even our motor-cars, steam-engines, and other forms of engines derive their energy from the same "bottled sunshine". Coal is composed of plant remains from vast primeval forests that must have existed for millions of years and formed enormously thick beds of almost pure humus. Oil is thought to have been derived from animal remains, the food-stuffs in which must have been made by plants. Thus when we ride in a train or an aeroplane or motor-car (or even in a tram or trolley-bus driven by electricity generated by steam raised in coal- or oil-fired boilers) we are using energy stored up by leaves aeons ago. From leaves to a fast aeroplane seems a far cry, but the connection is there if we care to trace it.

Metabolism

By the metabolism of a living thing we mean all the chemical changes which take place within it. The main features are the feeding or nutrition, the assimilation (into the living protoplasm) of the substances thus prepared and their use in respiration and in the synthesis of new protoplasm. Minor details are the whole range of lesser chemical changes which are carried on in such processes as the formation of enzymes in the digestive and other glands, the synthesis of vitamins and hormones, and the storage and subsequent release of stored foods.

While it is true that the vast majority of animals feed on solid plant or animal food-stuffs and that all green plants,

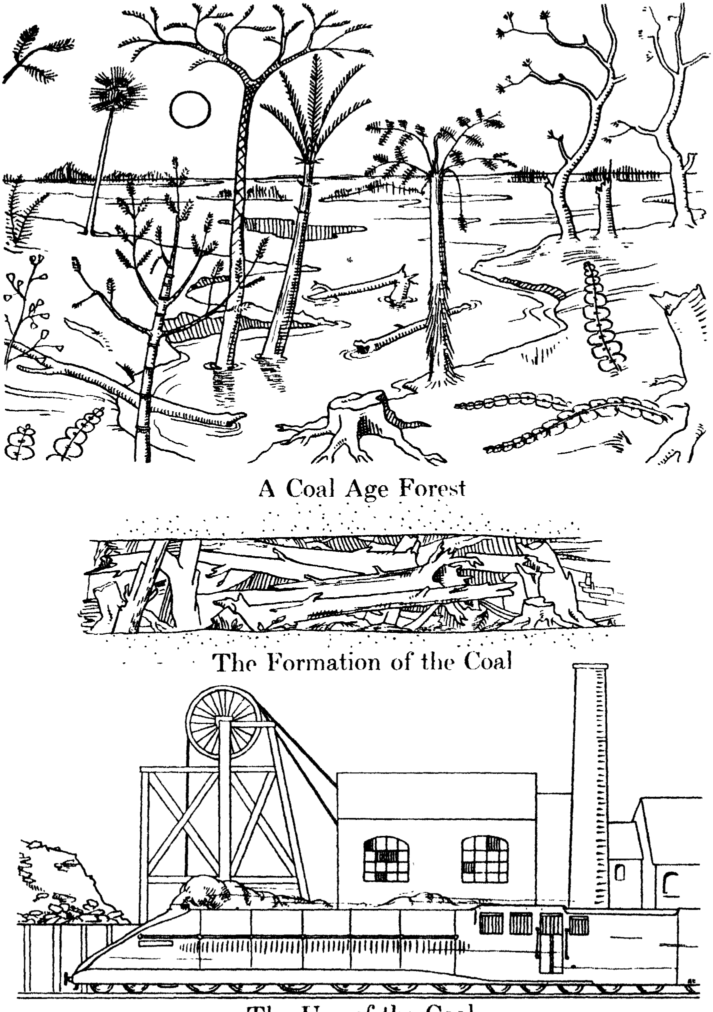


Fig. 69. The story of coal: an example of an "Energy Chain". (After Seward and Vulliamy.)

being possessed of chlorophyll, make their own food, there are exceptions to these general rules, for certain living things have found other ways of "making a living".

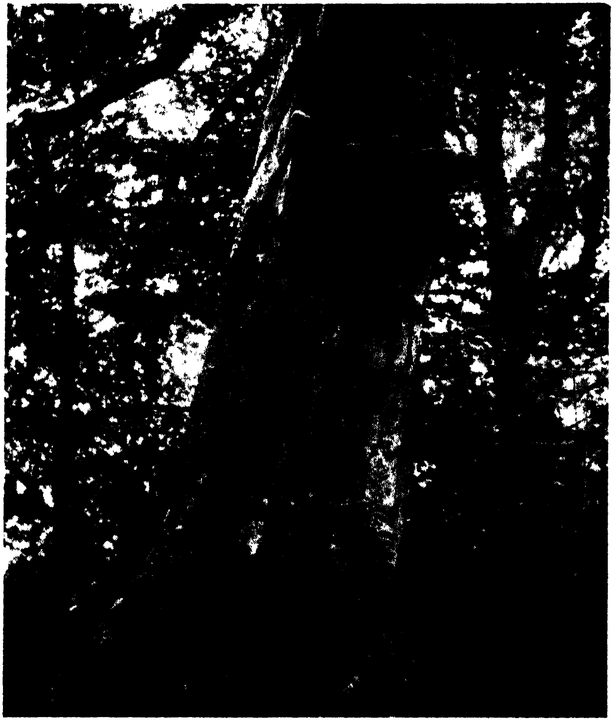


Fig. 70. The trunk of an old beech, showing a large wound, caused by the loss of a branch. A parasitic shelf-fungus has gained entrance through the wound and is growing on the tissues of the tree: note the large spore-producing body which it has formed. Note also the partial healing of the wound. [Photo: R.D.G.]

PARASITES

Among these exceptions are parasites—plants and animals which live on or actually within other living things, sucking

the blood or sap of the *host* (as the victim is called) or absorbing the food digested by the host for its own use. Examples include those of the bacteria which cause disease, tapeworms living in the intestines of such animals as dogs, pigs and men, and fungi growing on living plants or animals. Mistletoe is a *semi-parasite*: since it has chlorophyll, it makes part, at least, of its own food as other green plants do, but sucks its supplies of water and salts from the tree on which it grows. Obviously it is not always easy to draw the line between parasitism and ordinary animal feeding.

Parasites are of great significance to man in his attempts to control nature. In places where he is trying to prevent the spreading of unwanted plants or animals (e.g. prickly pear in Australia or the cotton-boll weevil in U.S.A.) the introduction of suitable parasites may be of great assistance. Most parasites, however, are a very definite nuisance to us: the ravages of rust fungi, which live on wheat, reduce the value of the world's annual crop by over £60,000,000.

When we compare parasitic plants and animals with normal living things of similar types we find that in many cases they are very much simpler. Some people speak of them as being "degenerate", but, while it is true that certain of their parts are often very much reduced, it is also true to say that in some respects they are distinctly specialised for their mode of life. In the same way, the clothes we wear for outdoor games or for swimming are simpler than those we normally wear; this again is an example of specialisation for a particular purpose and not of anything degenerate.

Thus tapeworms live by soaking up digested food from the intestines in which they live and so we are not surprised to find that they have no food canal, but absorb food over their entire surface. They also have no need to move about to seek their food, and again we find that they have very few muscles and none of the usual sense organs. On the other hand, tapeworms have to live in an actively moving intestine and on their heads we find suckers and hooks which attach them to the intestinal wall, and which would not be present in an ordinary animal.

The most serious problem which a parasite such as a tape-

worm has to face is the establishment of its offspring in the intestines of a suitable host. The first step towards the solution of this problem is the production of an absolutely enormous number of eggs. The part of the tapeworm immediately behind the head is continuously engaged in budding off new segments. Each of these grows by the absorption of food from the host,

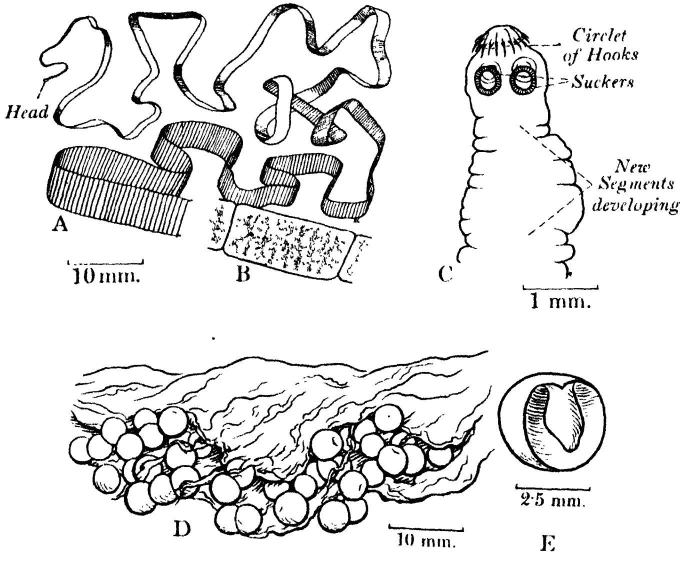


Fig. 71. The Tapeworm. A, The first few inches of a specimen several feet long, showing some of the hundreds of segments of which the tapeworm is composed. B, A completely mature segment, containing numerous eggs, from the end of the specimen. C, The head, enlarged. D, Embryos on connective tissues in the abdomen of a rabbit. E, A single embryo opened to show the partly developed head of the tapeworm within. (A, B and D, about natural size. C, $\times 10$. E, $\times 4$.)

the older segments being pushed further and further down the intestines by the younger segments which are following it. Each develops a full set of reproductive organs and finally several hundred eggs. Once the eggs are mature, the segment breaks off and passes out of the host with the faeces. Since the

animals which the tapeworm parasitises are normally carnivorous animals, the eggs cannot pass into them directly. What happens is that the eggs are eaten by, and hatched within, herbivorous animals such as rabbits. Here the embryos develop only so far (they can commonly be seen as small bladders on the connective tissues holding the stomach in a wild rabbit). The development is completed only if the intermediate host (that is, the rabbit or similar animal) is eaten by an animal in which the mature tapeworm is capable of living and if the embryo is not damaged in the process of being swallowed.

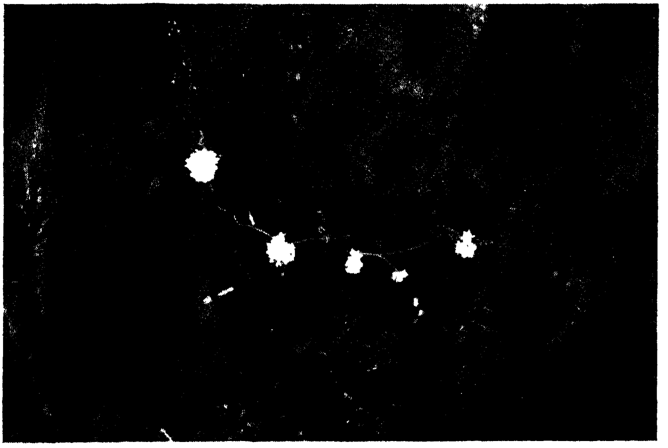


Fig. 72. Dodder, parasitic on heather. [Photo: R.D.G.]

Dodder is a flowering plant parasitic on gorse, heather, clover, etc., forming a tangle of fine red threads which spread in all directions over the host plant. Like all other parasitic plants, it has no chlorophyll and no ordinary leaves, nor has it (except when germinating) any roots drawing water and salts from the soil. It has, however, large numbers of tiny sucker-roots or *haustoria* which penetrate to the veins of the host and draw out food.

SAPROPHYTES

Similar to parasites are saprophytes—plants which feed on the dead remains of living things. (Note that the term is reserved for plants only: corresponding animals are called scavengers.) We shall have more to say about the importance of saprophytes in a later section (p. 126): here we need only point out that they are devoid of chlorophyll and ordinary leaves and include a few flowering plants such as the bird's-nest orchid and the yellow bird's-nest which feed on dead beech leaves, and *all* the fungi which are not parasitic. As examples of saprophytic fungi we may mention mushrooms which feed on dead plant remains in the soil or in a dung heap, the many other fungi which are saprophytic on dead wood, and moulds which live on the food in our larders.

Fig. 73. The "Yellow Bird's-nest" (*Monotropa*), saprophytic on dead beech leaves and roots.
[Photo: R.D.G.]

One of the commonest of these mould fungi is *Mucor*, or black mould, which grows on bread stored under damp conditions. Each plant of *Mucor* starts from a minute spore borne by air currents from another plant. If the conditions are suitable, the spore grows a small white thread or *hypha*, which soaks in food and so makes further growth possible. The hypha branches and multiplies until there is a whole mass, or *mycelium*, of hyphae[1]

[1] Compare Fig. 4. The mould there illustrated is *Aspergillus*, which is very similar to *Mucor*.

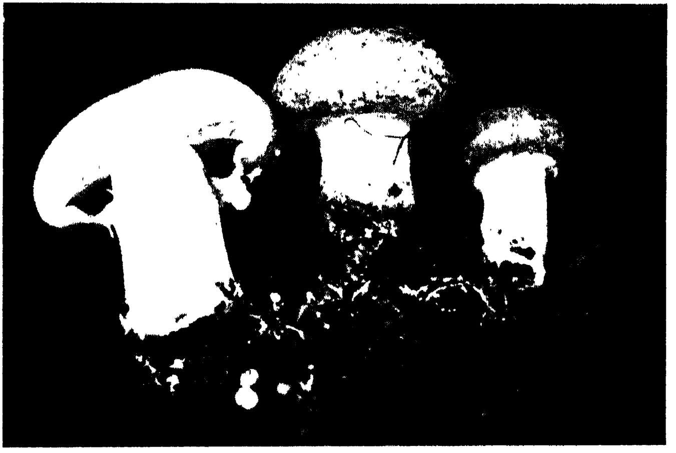


Fig. 74. Group of mushrooms, one of which is cut in two to show the "gills" on which the spores are formed. Note also, in the soil, some of the white threads, or "hyphae". See also Fig. 118*a*. [Photo: R.D.G.]

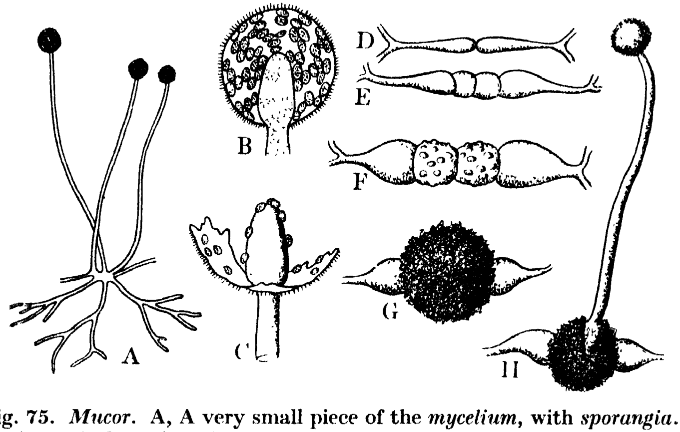


Fig. 75. *Mucor*. A, A very small piece of the *mycelium*, with *sporangia*. B, A vertical section through a sporangium. C, A sporangium, after opening and discharging its spores. D–G, Stages in the formation of the zygote. H, Germination of zygote to form a sporangium.

ramifying in all directions. After a time, the *Mucor* begins to reproduce. Most commonly this involves the formation of large numbers of spores in small black *sporangia* borne on hyphae projecting above the main mass of the mycelium. Sometimes, actively growing hyphae meet in pairs and each hypha of the pair cuts off its tip. These pairs of hypha tips join together, or conjugate[1] and the resulting *zygote* grows a thick black wall. Since this contains a comparatively large amount of food, it is able to rest for a longer period than a spore. If the zygote is carried to any place where conditions are suitable for active growth, it breaks open and forms a single sporangium within which new spores develop.

Carnivorous Plants

Among the most interesting of living creatures are the plants that trap and digest small animals—the so-called carnivorous plants. There is a little poem appropriate to this discussion:

> What's this I hear
> About the new Carnivora?
> Can little plants
> Eat bugs and ants
> And gnats and flies?
> A sort of retrograding;
> Surely the fare
> Of flowers is air,
> Or sunshine sweet:
> They shouldn't eat,
> Or do aught so degrading.

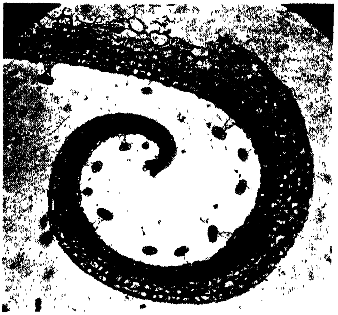
Luckily these plants are comparatively few in kind and are able to deal only with minute animals and so play a relatively unimportant part in nature, but it is easy and exciting to imagine that they might have been large, numerous and dangerous!

These carnivorous plants frequently live in marshy places and particularly in such locations as have water poor in nitrogen salts. We have pointed out that these salts are

[1] Compare the reproduction of Spirogyra (p. 27) and the reference on p. 226.

A

B



C

D

Fig. 76. Carnivorous plants.

A, Butterwort growing in the New Forest (× ½).
B, A thin section of a butterwort leaf, as seen under the microscope: note the glands which secrete enzymes for digesting the prey. (× 20.)
[Photos: R.D.G.]
C, Part of a plant of the common bladderwort. (About natural size.)
D, A single trap with two "victims". (× 15.)
[Photos: F. E. Lloyd.]

essential for the synthesis of amino-acids. Plants in such situations, then, might find it hard to obtain sufficient nitrogen for this purpose. By feeding partly upon meat they are able to get their amino-acids "ready-made"—i.e. they behave like animals. We must remember, however, that these plants *do* have chlorophyll and can make sugars for themselves, so they are not entirely animal-like in their feeding.

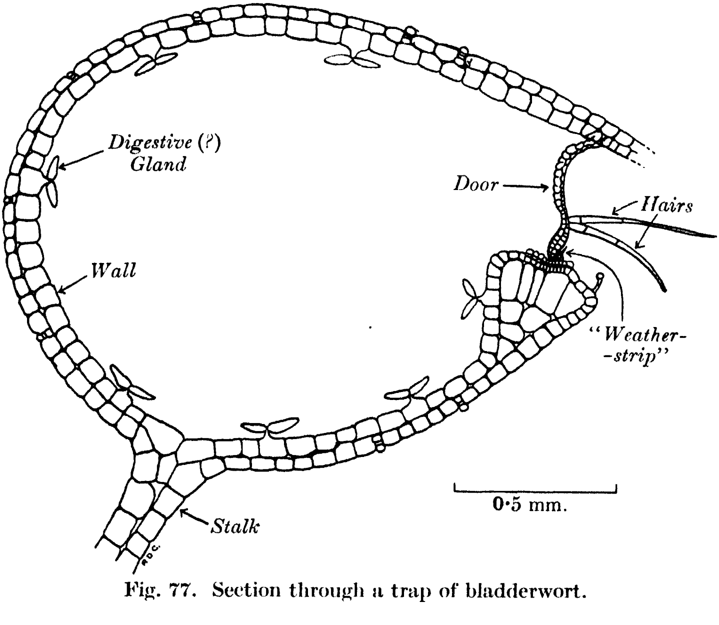


Fig. 77. Section through a trap of bladderwort.

There are many ways in which carnivorous plants trap their prey. Some, like the sun-dew and butterwort of our bogs, have sticky leaves with little, enzyme-secreting glands (just like those of the animal stomach) upon them. The fly or other tiny animal that lights upon the leaf sticks and is digested by the enzymes.

Others have leaves like steel traps, which close quickly upon the unfortunate animal that touches the trigger hairs.

Such a plant is the remarkable Venus' fly-trap (Fig. 117) that grows in a small area of the United States.

Perhaps the most remarkable of all is the bladderwort. This queer plant (of which there are several hundred kinds) has little, almost spherical, under-water traps, each of which has a water-tight door at one end. The trap pumps out water,

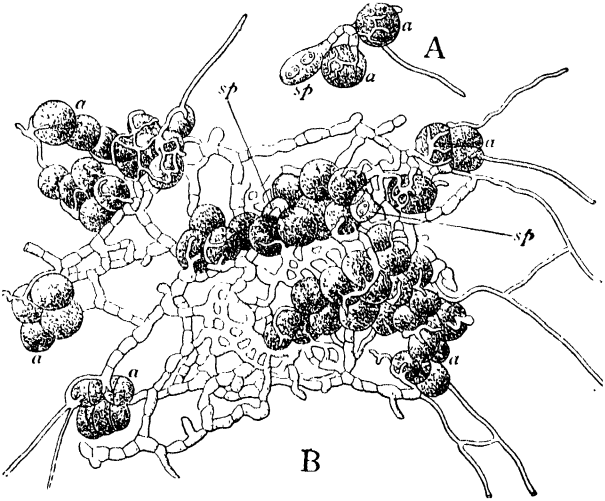


Fig. 78. A small portion of a lichen. Note the algal cells (*a*) embedded in a mass of fungal threads. A, A very young portion of the lichen: a germinating fungus-spore (*sp.*) has seized upon two algal cells. (× 400.) [From Scott, after Bonnier.]

its sides becoming dimpled in the process. It is then in the set condition. If a small aquatic animal touches the bristles on the door, the door flies open, the side walls spring out again, and water is sucked in to replace that pumped out. Usually the little animal is carried into the trap by the rush of water and once inside escape is impossible, for the door snaps to behind it and cannot be pushed open from within. As in the other plants mentioned, digestive enzymes are secreted by glands within the trap and the animal is digested.

Symbiosis

Symbiosis means "living together" and there are a number of cases where two living things *do* exist together without either of them becoming completely parasitic on the other. On the contrary, in at least some cases there seems to be a mutual advantage. For example, hermit crabs (so called because they protect their soft abdomens with mollusc shells) are often found with sea-anemones on their shells. This is not mere coincidence, for when such a crab changes its shell for a larger one, as it does at intervals, it deliberately moves the anemone across to the new shell. Apparently, the crab gains by securing a certain amount of disguise and the anemone is able to feed on bits from the crab's meals.

In plants we find many examples of this symbiosis. All *lichens* are composed of fungi living symbiotically with tiny green algal cells. The algae make food both for themselves and for their partners and are protected from drought by the fungal threads around them, so that they can grow on walls, tombstones and other exposed places where nothing else can live. A most interesting feature of such a partnership is the individuality of the lichen, comparable with the individuality of a chemical compound. It is more than a mere mixture of two plants: it has its own peculiarities and even makes certain acids, for example, which are not found elsewhere.

The bacteria which live in the root nodules on peas and beans and related plants get food from their partner plants and give back salts in return (p. 126).

THE SOIL

Soil consists of rock particles of various sizes, from small stones and sand grains down to clay particles a thousandth of a millimetre across, together with pieces of humus—decaying portions of plant and animal remains. Between the soil particles there are usually spaces filled with air, while on the surface of each particle is a film of water. Both the air spaces and the films of water connect with one another so that the air and water can move in all directions from one part of the soil to another through the network of capillary spaces.

From the soil, plants require water and salts—and their roots require oxygen (p. 149). A soil which is mainly sand has abundant air spaces but does not retain much water, while pure clay is very tenacious of water without having any air spaces at all. Humus is a very important constituent of soil since it is a valuable source of salts and it helps to retain water. Decaying humus, however, forms an acid which is not

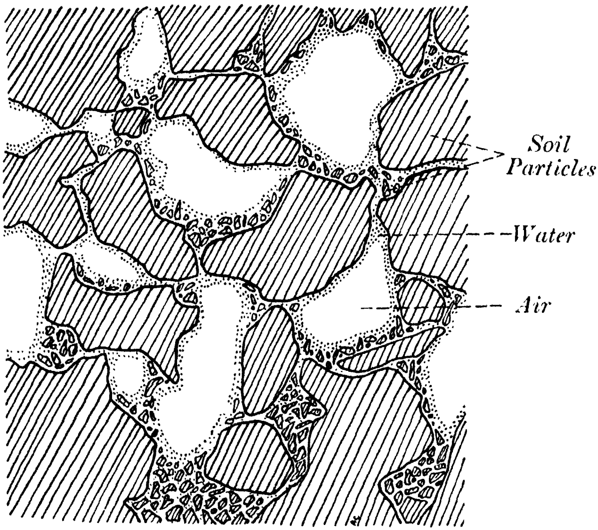


Fig. 79. Diagram of the structure of the soil. (× 40.)

normally neutralised unless chalk (or limestone) is present.[1] If a soil becomes very acid, few plants can grow on it. Other plants cannot tolerate a high proportion of chalk. A good soil, therefore, is one which is neither too acid nor too chalky and in which there is a good mixture of particles of various sizes together with humus: such soil is called a *loam*.

Anything which helps to loosen the soil—digging or ploughing, the burrowing of earthworms or the action of frost—improves it by allowing air to get to the roots and to

[1] See also p. 131, § 13.

the soil bacteria more easily. Water also moves more readily in a fairly loose soil, provided that the soil is not too dry.

The supply of salts in the soil is very limited and only small amounts are obtainable from the chemical breakdown of the soil particles themselves. Consequently, it is necessary to replace the soil salts as they are used up. Under natural conditions, this replacement is carried on automatically by the release of salts during the decay of the soil humus by saprophytic bacteria.

These bacteria are present in the soil in enormous numbers —many millions per cubic centimetre!—and while they actually absorb part of the material of the humus they carry out a whole series of chemical changes on the remainder. Chief among these are the changes by which proteins are broken down by various bacteria, first to amino-acids and ammonia and then in part to nitrogen and in part to nitrates. Other bacteria in the soil—and these perhaps are the most important of all—have the power of "fixing" the nitrogen of the air to form nitrates. Some of these organisms are found free in the soil while others live in the small swellings, called *root-nodules*, on the roots of plants of the pea family—peas, beans, clovers, vetches, etc. A more copious formation of root-nodules is often induced by "inoculating" the soil with the bacteria which normally live in them. Only where some of these bacteria enter the roots of the young clover plants from the soil, are nodules formed and nitrates made. The nitrates, whether formed from the humus or from atmospheric nitrogen, are taken in by the plants which need them and used in the building up of new proteins. Thus we have a "circulation of nitrogen compounds" in living things.

If plants only were concerned in the nitrogen cycle, it would be a very slow process indeed; for the dead remains of plants are very resistant to decay. Actually a very large proportion of plant material is eaten, sooner or later, by animals; and the major portion of this food is used by the animals for the production of energy. In the preparation of this energy food in the liver of the animal (p. 102) the nitrogen part of the protein molecule is converted to urea, which is later eliminated from the animal body in the urine. Soil bacteria can very

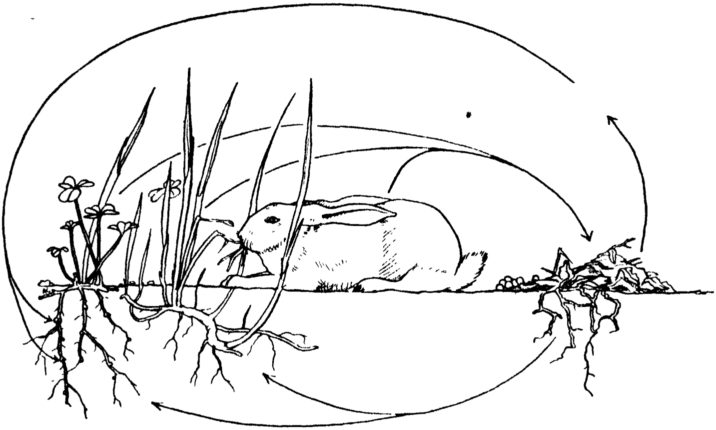


Fig. 80. The Nitrogen Cycle. The rabbit feeds on grass and clover; dead remains, dung, urine, etc., are decayed to give nitrates (absorbed by roots) and nitrogen (used by root-nodules of clover).

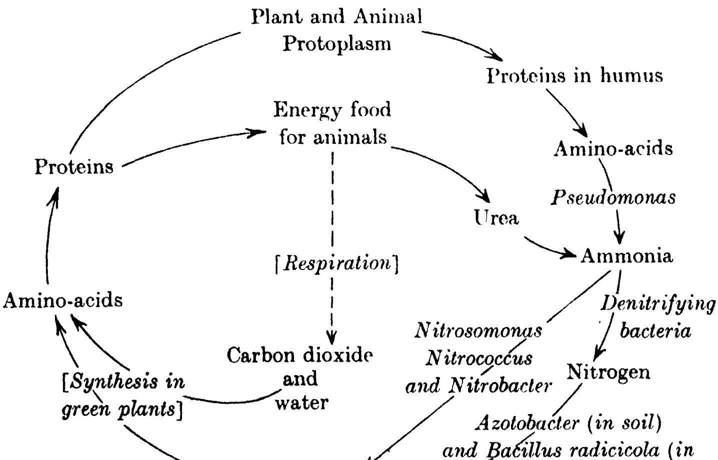


Fig. 81. Summary of the nitrogen cycle.

rapidly convert the urea to ammonia—and then, of course, to nitrates again. Thus, animals play an important part in the nitrogen cycle by speeding it up considerably: without their intervention the whole tempo of the chemical changes on which life depends would be very much slower. We have attempted to summarise all these changes in the accompanying diagrams: the names on some of the arrows are those of the bacteria responsible for the various chemical changes.

It will now be realised that we have here another example

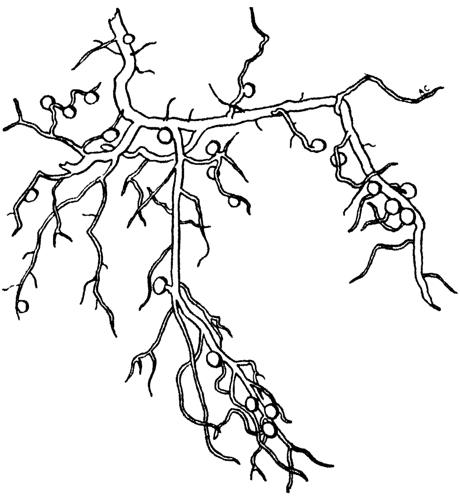


Fig. 82. The root-nodules on a small piece of the root of a runner bean.

of the interdependence of living things: without the work of these soil bacteria and the decay which they produce, other life could scarcely carry on. The bacteria themselves benefit by using the energy, set free by the chemical changes, to synthesise sugar and other food substances in almost the same way as do green plants. The only difference is that while green plants use the energy of light and so are said to carry on photosynthesis, the bacteria use chemical energy and the process in their case is called *chemosynthesis*.

If we remove the plants from the soil when they are mature—as is usually the case in farming and in gardening—the supply of salts is gradually exhausted and the soil becomes poor in humus also. Albrecht has recently calculated that the removal of the crops and mature cattle from a fertile 200-acre farm involves an annual loss of salts worth over £300. It is necessary to make up for such removals, as far as this is possible. Gardens are manured with stable manure or artificial fertilisers are added to the soil. The fertiliser can supply the nitrates and other salts necessary (and may play an even more important part by encouraging the soil bacteria) but the manure has the additional advantage of increasing the humus content of the soil. Farmers do not always find this so easy, especially in Australia and the Americas where farms may be very large—and in these areas the salt content of the soil is dropping.

A well-known method of renewing the supply of nitrogen compounds is by arranging a "rotation of crops". A common rotation is corn, root crop and clover—the latter enriching the soil through the synthesis of nitrates in its root-nodules. Similarly, gardeners and allotment holders often divide their ground into three plots and grow different crops on the different plots in rotation. One of the crops thus grown on different parts of the garden in successive years is always a "leguminous" one: that is, peas or beans, or both.

The humus content of the soil can be increased by sowing a quick-growing crop such as mustard and ploughing it in while it is still green.

PRACTICAL WORK

1. Examine a nephridium (kidney) of a freshly-killed earthworm for parasitic threadworms. Parasites of various kinds will also be found on and in most other wild animals.

2. Examine museum specimens and microscope slides of tapeworm.

3. Examine parasitic and semi-parasitic plants and trace their connection to the host plant.

4. Spread cress seeds thickly on soil in a flower pot and invert a jam-jar over them to keep them in a very damp atmosphere. Note the fungus (*Pythium*) which grows on the cress seedlings—parasitically at first and later, when the cress dies, saprophytically.

5. Saprophytic fungi (moulds) will also grow on bread, cheese, jam, etc., kept in a warm, damp atmosphere: e.g. place the food on an egg-cup in a saucer of water and invert a jam-jar over it.

6. Examine specimens of carnivorous plants. Sun-dew can be grown indoors if kept in a saucer or soup plate of bog-moss and given abundant soft water. Try feeding it with tiny particles of meat, white of egg, sand, etc., and notice the results.

7. Cut up some butterwort leaves, place them in a muslin bag in a dish and pour warm milk over them. Compare the result with the effect of rennet (a digestive enzyme) on milk.

8. Dig up roots of peas, beans, lupins, or other leguminous plants and examine the root-nodules.

9. Composition of soil.

(*a*) Shake some soil thoroughly with water in a glass jar and leave it to settle. Notice the layers of different sized particles (sand, silt and clay) and the humus which floats at the top.

(*b*) To show the presence of air put a flower-pot of soil in a bucket of water and notice the bubbles which rise.

(*c*) Weigh some fresh soil in a weighed evaporating dish and dry it in a steam oven for some hours. Weigh again, reheat and reweigh until there is no further loss in weight. Calculate the percentage of water present.

(*d*) Weigh some of the soil dried in (*c*) in a weighed crucible and heat it, carefully at first and then to redness to burn away the humus, stirring occasionally with a clean nail. Cool, reweigh, and calculate the percentage of humus present.

(These experiments should be carried out with different types of soils —e.g. from garden, field and wood, subsoil, leaf-mould, etc.)

(*e*) To test for salts, shake up some soil with distilled water and leave it for several hours until it has completely settled. Filter the clear liquid (several times if necessary until the brown colour due to clay particles has disappeared). Evaporate part of the liquid to dryness and test another part for nitrates by adding 0·5 per cent. diphenylamine dissolved in conc. sulphuric acid. (This gives a deep blue colour in the presence of nitrates.)

10. To demonstrate the presence of bacteria in the soil, put a little milk in each of two conical flasks and sterilise it (i.e. kill all the bacteria in it by boiling gently for a few minutes). Plug the flasks tightly with cotton-wool and leave them to cool. Then add a little garden soil to one: leave the other as a control experiment for comparison. After a day or two smell the contents of the flasks and examine a drop of milk from each under the high power of the microscope.

11. To investigate the properties of different soils (e.g. a very sandy soil, a clay soil and a good garden soil) try the following experiments.

(*a*) Place a perforated metal disc (or a loose plug of cotton-wool, wetted) in a filter funnel and place a layer of *dried* soil on it. Pour on a measured volume of water and measure the volume of water which passes through.

(*b*) Fill similar jars or tins with equal quantities of different damp soils. Place them in a warm place, weigh daily and compare the rates at which water is lost. Repeat the experiment with two samples of the same soil, pressing the surface down hard in one case but powdering it in the other.

(*c*) Cover the bottom of a wide glass tube (e.g. lamp chimney) with muslin and fill it with dried soil. Place it in water and note the result.

12. Take a clod of soil from a ploughed field in autumn, leave it exposed to frost and rain during the winter and watch the result.

13. Shake up some soil containing a high proportion of clay with (*a*) water, (*b*) lime water. Note how the lime causes the clay particles to bunch together. This is another way in which the use of lime can improve clay soil.

(For other experiments on soil see Sir E. J. Russell's *Lessons on Soil*.)

CHAPTER VIII

INTERNAL ENVIRONMENT AND TRANSPORT

External and Internal Environment

Since protoplasm consists of about three quarters water it needs to be bathed in liquid: otherwise it will be in grave danger of death by drying up. Such organisms as Amoeba and Spirogyra are bathed by the water of the pond or stream in which they live and their presence in such water proves that it constitutes a suitable *external environment* for them. For larger organisms, however, there must be an actual liquid *within* the body bathing the protoplasm of all the different parts and this liquid constitutes a very important part of the *internal environment.*

In large plants growing on land we find not only the sap within the cells themselves but water taken in by the roots saturates every part—even the cellulose cell walls. Thus the cells of the plant are constantly bathed in liquid. In such animals as the Arthropods (insects, crabs, spiders, etc.) there are practically no blood vessels but a large blood space in which the organs lie: thus the blood itself bathes every part. In most larger animals, however, all parts are bathed in *lymph,* which is blood (without the red corpuscles) which has oozed, or filtered, out of the blood vessels. You can see lymph itself when you break open a blister.

Protoplasm becomes used to the conditions under which it normally lives and will fail to function properly if those conditions are greatly changed. Amoeba will live in a pond of almost pure cold water, but human protoplasm has become used to, and so needs, an extremely complex mixture of substances—food, oxygen, salts, hormones, etc.—in solution in the lymph. It also needs a temperature of, or very close to, 98° F.; variation by a very few degrees results in death. While our bodies can stand very considerable variations in the conditions around us—i.e. in the external environment—the

various factors of the internal environment must be very closely controlled.

This has been well illustrated by the case of miners working at Salford. Here the mine is so deep that the atmosphere is extremely hot and the miners lose large quantities of perspiration. At one time they drank correspondingly large quantities of water. They were subject to various disorders of the muscles and it was suggested that, since perspiration contains salt as well as water, the troubles were due to the body's losing too much salt. This was proved to be the case and now Salford miners drink dilute salt water and are free from their previous troubles.

TRANSPORT AND CIRCULATION

Going back to Amoeba and Spirogyra again, you will remember that we pointed out that diffusion plays quite an important part in their lives. In Amoeba oxygen diffuses in over the whole surface, and

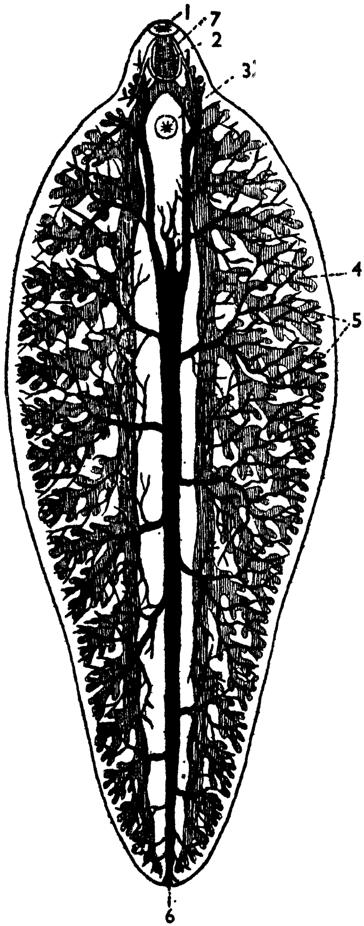


Fig. 83. The Liverfluke, an animal parasitic on sheep. This animal has no transport system at all and the food canal (shaded) and excretory organs (black) have, therefore, to be richly branched so that they can reach every part of the body. 1, Mouth. 2, Throat. 3, Sucker. 4, Branch of food canal. 5, Branch of excretory organs. 6, Excretory pore. 7, Main nerve centre. (×3.) [After Shipley.]

carbon dioxide diffuses out with equal ease (the reverse, of course, is true for Spirogyra in light) and water passes in by diffusion also. Now diffusion is a very slow process and while it is rapid enough for small organisms it is too slow for anything with a diameter above about a tenth of an inch. In larger organisms, therefore, there must be a transport system in which something actually circulates, carrying the necessary food and oxygen to the liquid which bathes the protoplasm and carrying away the waste products.

In the larger plants there are really two separate transport systems—one for the water and salts and the other for the food made in photosynthesis. In the larger animals, the blood flowing in the blood vessels is responsible for transport.

TRANSPORT AND CIRCULATION IN PLANTS

Many of the simpler plants live in water and so can absorb water and salts and exchange gases at all points of their surface. Most of these plants are relatively small and nearly all the cells can get light enough to make their own food. The larger plants, and especially those that live on land, have to face several problems. In the first place they can absorb water only through their roots and their upper parts actually lose moisture by evaporation (p. 165). Therefore *water* must be carried from the roots to these upper parts. Secondly, they have to develop massive skeletal tissues to withstand the mechanical strains of a life on land and the inner cells of these tissues (as well as the underground roots) cannot make food since light does not reach them. *Food*, then, must be carried from the chlorophyll-containing leaf-cells to these other cells. Thirdly, these inner cells need *ventilation* since they respire and so need to receive oxygen and to get rid of carbon dioxide.

The larger land-plant, then, must have transport systems for the carriage of water, food and gases. Food and water are carried in the *phloem* and *xylem* (wood) respectively. These tissues make up practically the whole of the roots, trunk and branches in a tree (Fig. 84) while in other plants they are the main components of the veins.

Wood contains mainly strengthening fibres and long tubes known as *vessels*. These vessels have very thick walls—except for numerous pits through which water can soak from one vessel to another—but contain no protoplasm at all and have

Fig. 84. Section of a three-year-old lime twig. Note pith at centre, three rings of wood (*xylem*), the dark line of the *cambium* (p. 239), the *phloem* in triangles and the bark. One *lenticel* (cf. Fig. 98, p. 154) is seen. (× 10.) [Photo: R.D.G.]

no cross walls (Fig. 86). In the sap-wood many of them are completely filled with water. Certain living cells are also present. The inner (heart) wood in a tree is dead and usually almost dry: it gives only mechanical strength to the trunk.

The chief cells in the phloem are so-called *sieve-tubes*. These again are tubes, each composed of cells stacked one above

another and communicating through perforated, sieve-like, cross walls (Fig. 86). Through the perforations pass strands of protoplasm, which show a streaming movement. One curious point about a sieve-tube is that it contains protoplasm but no nuclei. Apparently its functions are controlled by the nuclei of the small *companion cells* which are usually found adjacent.

Water absorbed by the roots passes up to the leaves through the vessels of the sap-wood and veins. Quite how this happens is not completely understood, though biologists have been working on the problem since the time of Nehemiah

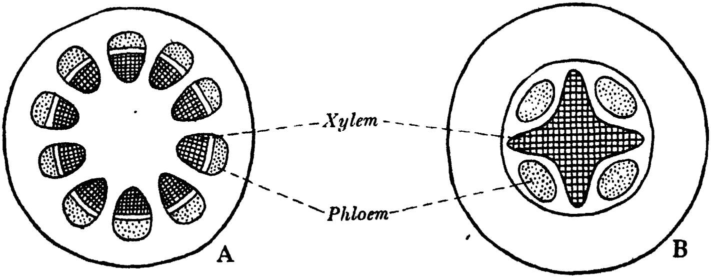


Fig. 85. Sections across (A) the stem and (B) the root of an "herbaceous" (i.e. non-woody) plant. The bundles in the young stem form a hollow cylinder—the best arrangement for withstanding *bending* strains (cf. p. 40). In a young root, on the other hand, the xylem which is the strongest part forms a central strand well adapted to withstand the *pulling* strains to which roots are specially subject.

Grew, who wrote *The Anatomy of Plants* in 1682. There is no doubt that water and salts move upwards in the sap-wood: moreover, they move rapidly. How water reaches the tops of tall trees (Eucalyptus and Redwood trees may be over 300 feet in height) we do not know. It is not forced up but seems to be drawn up by suction due to evaporation from the leaves. An ordinary suction pump lifts water only about 30 feet, but slender, continuous columns of water appear to have the strength of steel wires and so may be capable of going to great heights.

It has long been thought that food is carried in the sieve-tubes and it is now believed that the streaming of the proto-

plasm in these tubes is responsible for the actual movement of the food. Certainly diffusion is too slow a process: for example, careful measurements have shown that the growth of a young potato is so rapid that the transport of sugar to it (for conversion to starch) is far more rapid than can be accounted for by mere diffusion. As in the case of water, some definite transport system would appear to be a necessity. That this

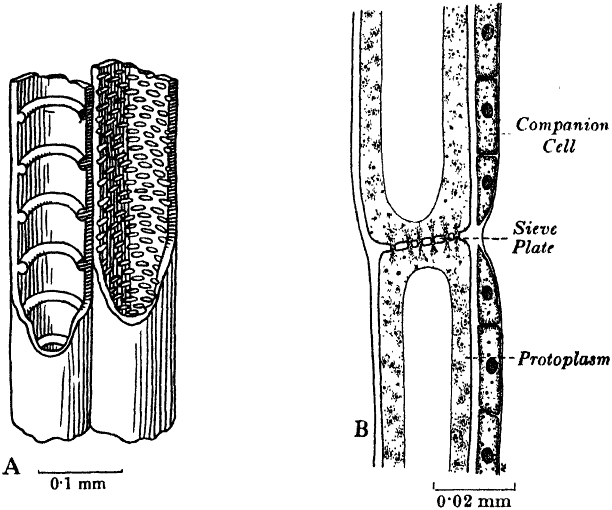


Fig. 86. Conducting cells in plants. A, Two vessels, showing the thickening of the walls. B, A sieve-tube. No nuclei are present, but the protoplasm is probably "governed" by the nuclei in the small adjacent companion cells.

transport system for food is the actual movement of protoplasm in the sieve-tubes is strongly suggested by the following experiments.

If a ring of the soft outer tissues (i.e. the bark and phloem) be removed from the woody stem, the movement of water is little affected but movement of food is almost completely stopped. This is regarded as good evidence that water moves in the wood and food in the phloem.

Another recent experiment is even more striking. Curtis succeeded in cooling the petiole (stalk) of a bean leaf by circulating cold water through a set of tubes closely surrounding the petiole. Down to about 6° C. nothing happened but below that temperature the movement of food-stuffs—but not the movement of water—ceased. The interesting thing is that at the same temperature of 6° C. the movement of protoplasm usually ceases! Again, we appear to have a proof that water

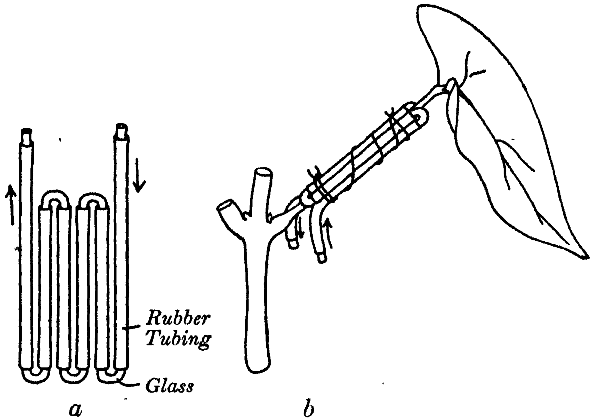


Fig. 87. Diagram of Curtis's experiment on transport in plants. Note the tubes for cooling, (*a*) before and (*b*) after arranging them around the petiole.

moves in the wood vessels which contain no protoplasm and that the food is carried by the movement of the protoplasm in the sieve-tubes of the phloem.

Little is known about the movements of gases in plants. The bark is provided with *lenticels*, crack-like openings which probably serve as ventilators (Figs. 84 and 98). There are air spaces between some of the cells and these communicate with these lenticels. In leaves, as we have seen in the discussion on photosynthesis, the gas exchange takes place through the stomata. We shall have more to say about this when discussing respiration.

TRANSPORT AND CIRCULATION IN ANIMALS

The circulating fluid in animals is blood. It differs a little in different animals and the following description will serve for the mammals including, of course, man. The liquid of the blood, the *plasma*, is a pale yellowish fluid and the red or bluish colour of the blood as a whole is due to the *red corpuscles* which float in the plasma. These are flat circular objects 1/3500 of an inch in diameter and contain a very important chemical, *haemoglobin*. This has the power of combining loosely with oxygen and thus enables the blood to carry far more oxygen (about forty times as much) than would be the case if all of it had to dissolve in the blood. Most other substances—digested food, urea, carbon dioxide—which are transported by the blood are carried in solution (though the red corpuscles take some part in carrying carbon dioxide). The plasma also contains in solution the salts, hormones, etc., which form a necessary part of the internal environment.

Two further very important functions of the blood must be mentioned. In addition to the red corpuscles (of which there may be as many as six million to the cubic millimetre) there are smaller numbers of various sorts of *white corpuscles*. These are more or less amoeboid in form and their chief functions are to make *anti-toxins* (p. 268) and to eat up the swarms of bacteria which find their way into the blood through the lungs, through wounds in the skin or through the injured tissues of a sore throat. Finally, there are substances carried by the blood which cause it to clot when a blood vessel is broken so that the wound is filled and bleeding stopped.

The volume of the blood in the body is about six litres. The heart pumps about 60 c.c. per stroke (which is equivalent to between 3 and 4.5 litres per minute) through each ventricle when the body is at rest. This may rise to nearly 35 litres per minute during strenuous exercise. Athletes can often increase their output several-fold without increasing the heart-beat rate: non-athletes cannot do this.

The red corpuscles of the blood are made in the marrow of the ribs, of the vertebrae and of the ends of the long bones. The average life of each is about a month. At the end of this

time they gradually break up in the blood stream: about a million do this every second. White corpuscles are made in marrow and in special lymph glands: their average life is about three weeks.

The blood is kept in movement by the heart, which acts as a great pump, and flows outwards through the arteries and returns through the veins. The *arteries* branch to every part

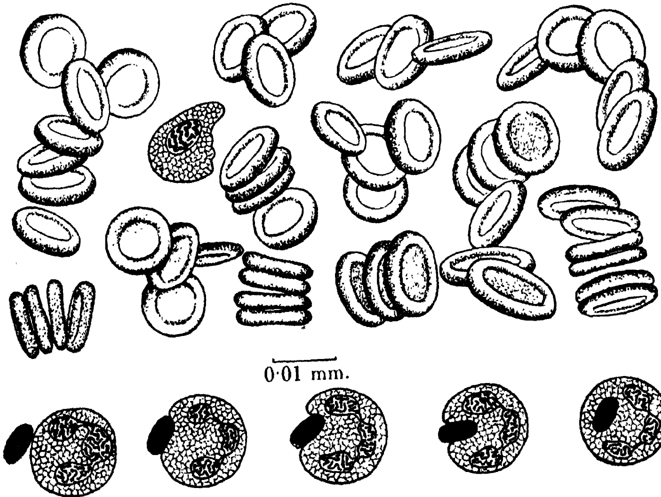


Fig. 88. Red and white corpuscles as seen in a very minute drop of human blood, and (below) stages in the eating of a bacterium by a white corpuscle. [After Cullis and Bond.]

of the body (except to cartilage, and to the inside of the brain and spinal cord, where the delicate nerve cells would apparently be injured by the throbbing of the pulse). Similarly, the *veins* collect blood from every part. At their final ramifications the arteries branch again and again to form a dense network of *capillaries*—blood vessels so fine that the red corpuscles have to proceed through them in single file, so thin-walled that not only the plasma of the blood but even the white corpuscles can ooze out from them, and forming so dense

a network that a single square millimetre in a cross-section of a muscle may contain a thousand of them! You will see therefore how well the capillaries are able to perform their function of bringing the blood into the closest possible contact with the protoplasm of the body cells. The lymph which oozes out of

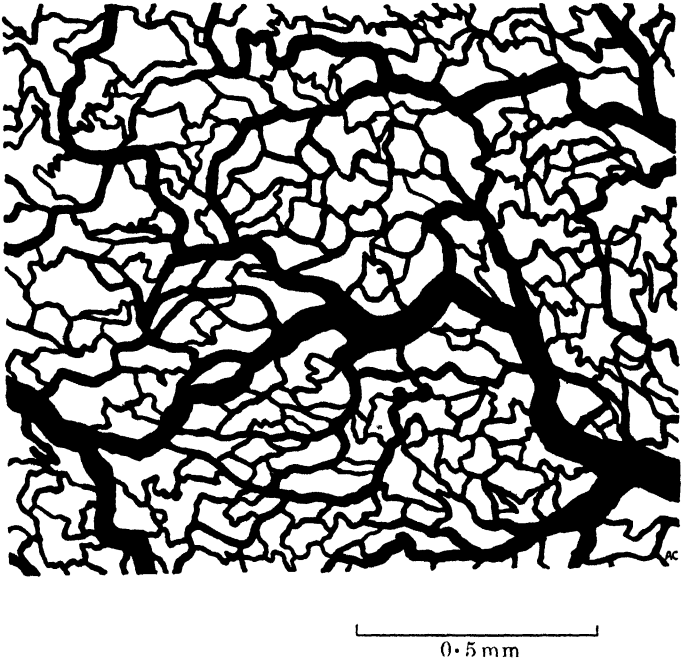


Fig. 89. Capillaries in 2 sq. mm. of the skin of a frog.
[See also Figs. 61 and 103.]

the capillaries and bathes those cells is collected by a special network of lymph vessels which join together and empty into the main veins near the heart.

The arteries carry blood under the high pressure generated by the pumping action of the heart, and they are able to withstand this high pressure because they have thick mus-

cular walls. Every time the heart beats a new wave of high pressure flows down every artery and consequently the walls of the arteries give a little. This is what causes the pulse, which we can feel in those parts of the body where arteries are close to the surface.

The veins which carry the blood back to the heart can be comparatively thin-walled since the blood is under a very low pressure. This is due to the fact that the heart is strong enough to pump the blood through the arteries and into the capillaries only. Once the blood leaves the capillaries there is not sufficient

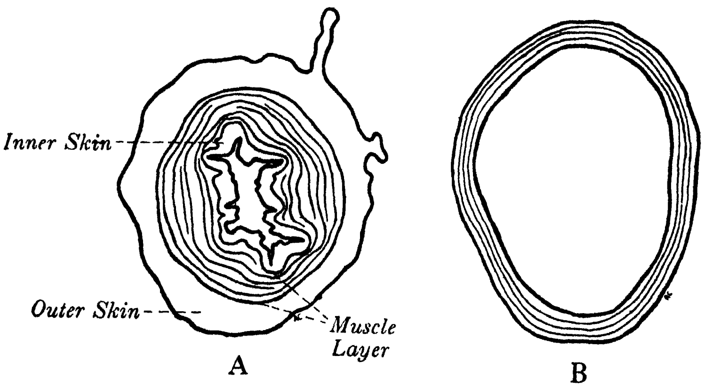


Fig. 90. Sections of (A) artery and (B) vein.

force to push it back to the heart, and its movement in the veins is due to another mechanism. At intervals there are valves so placed that blood cannot flow in the veins *away* from the heart. As we have said, the veins are thin-walled and consequently any movements of adjacent muscles squeeze them and so drive the blood towards the heart—the only direction in which it can move. Thus when we run, blood is driven along in the veins of the legs while depression of the diaphragm in breathing (p. 158) forces blood to move in the veins of the abdomen.

From this, there follows the important fact that if the veins in any part of the body are not emptied by muscle move-

ments they become choked with blood and little or no fresh blood can flow *to* that part, and with this fact in mind we can explain many things which would otherwise puzzle us. We find that if we make a big effort in a stationary position—e.g. hanging from the horizontal bar with arms bent—we become fatigued very rapidly. On the other hand, the free movements we make in running or swimming promote rapid circulation and so cause far less fatigue than would otherwise be

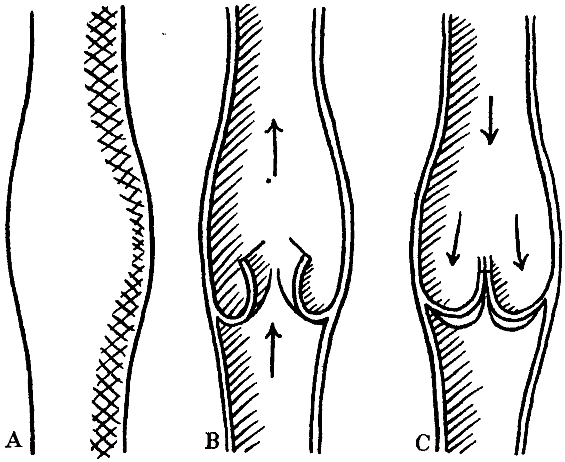


Fig. 91. Valves in a vein. A, The swelling on the vein which indicates the position of a valve. B, The valve open. C, The valve shut and preventing the return of blood. [Redrawn from Keith, *Engines of the Human Body*.]

the case. Again, we can explain why tight clothes are harmful. Tight garters or shoes will stop the circulation of blood in the feet and so keep them cold and subject to chilblains, while a tight collar will stop the circulation to the brain to such an extent that fainting or even death may result.

The actual geography of the arteries and veins is not very important. It is sufficient for us to know that blood is taken to and collected from practically every part of the body and that there is, in the mammals at least, a *double circulation*.

By this we mean that the whole of the deoxygenated blood returning to the heart from the various parts of the body is pumped to the lungs and then back to the heart again before it is passed out as oxygenated blood to the body once more.

Thus there are two streams of blood flowing through the heart and they are kept entirely separate by a division down the centre of the heart itself. Indeed we might say that each of us has a double heart or "two hearts that beat as one". Each part pumps about a gallon of blood per minute normally (though the amount is enormously increased when

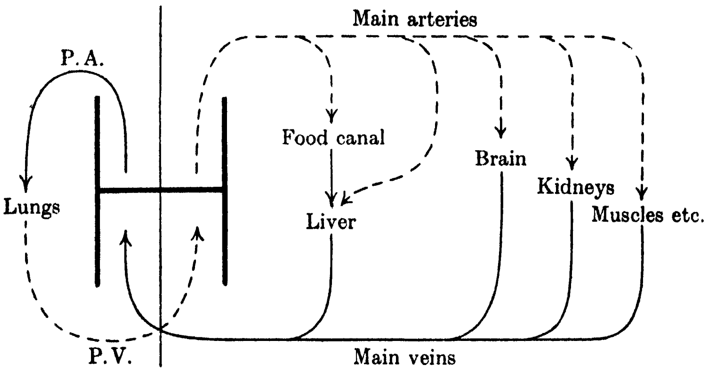


Fig. 92. Diagram of circulation of blood. H., Heart. P.A. and P.V., Pulmonary (Lung) Artery and Vein. ---- Red (oxygenated) blood. —— Blue (deoxygenated) blood.

necessary) and is composed of two chambers. Thus in each half we have an *auricle*, a thin-walled reception chamber, which receives the blood from the veins and pumps it into the *ventricle* which has thick muscle walls and is the main pumping chamber. There are *valves* in the veins, between the auricles and ventricles, and again where the arteries leave the ventricles. These, of course, are most important since they prevent the blood from coming back the wrong way and it is their closing that we can hear through the walls of the thorax if we listen to the working of the heart.

There are times when some part or parts of the body are

called upon for some special exertion, e.g. the muscles during strenuous exercise and, immediately after a heavy meal, the glands which prepare the digestive juices. Such special exertion requires a specially generous blood supply, and this is

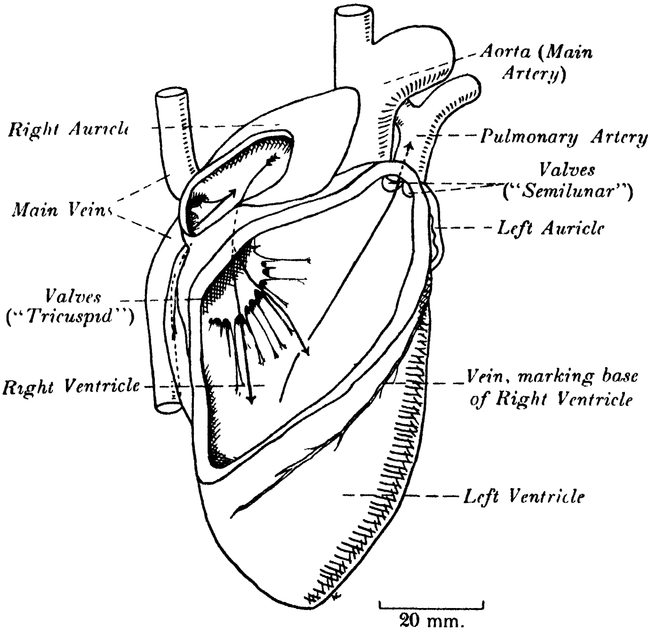


Fig. 93. A dissection of the right half only of a sheep's heart: the arrows indicate the movements of the blood. The drawing shows the blood vessels which open into the heart, except for the pulmonary veins. The left auricle, into which these open, is just visible.

secured by unusual dilation of the capillaries in the parts concerned. The results of such a dilation are seen in the flushing of the skin when it is hot (p. 180).

These dilations mean an increase in the volume which the blood has to fill. This is compensated by the partial or complete emptying of the body's blood reservoirs, of which the

spleen is the chief. Even this may not be sufficient in very severe muscular effort and then the blood supply to the food canal and liver and even to the kidneys may be almost entirely cut off. Because of this type of adjustment of the blood supply it is most unwise to put a strain on more than one set of organs at once. Immediately after a heavy meal it would put far too great a strain on the circulation, and on the heart in particular, to indulge in a hot bath, in swimming or other strenuous exercise. It is even more difficult than usual for us to think clearly at such times than when the blood supply to the brain is normal.

PRACTICAL WORK

1. Put the stem of a white flower, or a stem bearing a few leaves, in red ink; when the red ink shows in the petals or the leaves, trace the path by which it ascended by cutting the stem across at intervals of about an inch. The stem of a young balsam plant is sufficiently translucent for the course of the red ink to show through without dissection.

2. Cut small discs of sap-wood to fit on to a tap—some with the vessels running down through the disc and others with the vessels running parallel to the top of the disc. Fix them, one at a time, on to the tap with some sort of a clamp (e.g. a screw-on nozzle) and notice which will conduct water best.

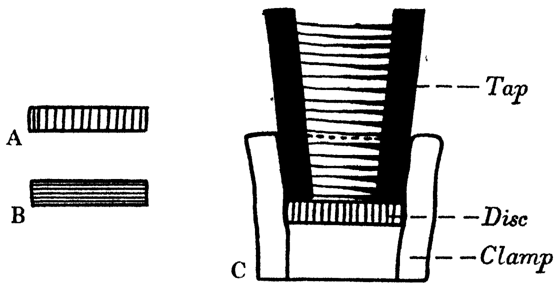


Fig. 94. Experiments with discs of wood.

3. Examine transverse and longitudinal sections of stems and roots. Details of the phloem can best be seen in cucumber or marrow stems.

4. Take a cut shoot of a woody plant and about two inches from the base make two cuts a quarter of an inch apart, right round the stem and down to the wood. Peel off the ring of bark, phloem, etc., between the cuts and smear the wound with a little vaseline to prevent it drying up. Leave the base of the twig in water and after a day or two compare it

with two similar uncut twigs, one in water and the other left without water. What conclusions can you draw concerning the conduction of water?

5. Take a cut shoot of willow 18 in. to 2 ft. long, strip the leaves from the lower half and "girdle" it in the manner described in the last paragraph. Place it in water so that the cut is well covered and place a similar uncut twig with it for comparison. After about a fortnight, roots should develop on the twigs. Remembering that these require food for their growth, what conclusions can you draw from your results, about the conduction of food in the twigs?

6. Tie a string tightly round the last joint of your first finger and bend the end of the finger over. Prick sharply just behind the nail (practically no pain will be felt here) with a needle which has been sterilised by heating in a flame for a second or two. A large drop of blood will exude. Put this on a microscope slide warmed to blood temperature and examine it under the high power. One or two white corpuscles may be seen moving about in the same way as Amoeba moves.

7. To study the colour changes in blood, make a dilute solution of haemoglobin with a drop of blood in a test-tube of water. Remove the oxygen from the solution by adding a very little powdered sodium hydrosulphite: note the change in colour. Dissolve more oxygen in the solution by shaking it up with air and notice the result.

8. With the aid of the microscope the actual flow of blood and movement of the corpuscles can easily be observed in the external gills of a very young tadpole, or in the tail fin of a somewhat older tadpole. The animals should be placed on a microscope slide with enough water to keep them damp and a very small drop of chloroform. The same thing can be seen in the web of a frog's foot: in this case, anaesthetise the frog by placing it for half an hour in 2 per cent. urethane solution.

9. The branching of an artery and of a vein can be seen very well on the inside of the skin of a frog.

10. Watch the heart beats in a frog which has been opened up immediately after it has been killed and notice the order in which the auricles and ventricles contract.

11. The heart beat of a living Daphnia (water-flea) can be watched under the microscope. The larvae of *Chironomus* or *Corethra* (fresh-water larvae known as blood-worms and ghost-larvae respectively) can also be used. Movement can be prevented by covering the specimen with a cover-slip supported at the corners by wax.

12. Take your pulse-rate when you are resting and immediately after strenuous exercise.

13. Dissect a sheep's heart to show the right side (Fig. 93) and then dissect the other side.

14. To examine the flow of blood in the veins, place one finger tip on one of the large veins in the wrist and with another finger stroke the vein towards the elbow. Notice how easy it is to push the blood out of the vein in this way. Lift the finger nearest the heart and in a few seconds lift the other finger: notice when the vein fills again with blood. Stroke a vein *down* towards the hand. Explain the results you observe.

CHAPTER IX

ENERGY

Living things use Energy

By energy we mean the power to move about and to do work. Thus a locomotive uses energy to haul a train and a crane must use energy to lift heavy weights. It is equally obvious that animals moving about need energy and that it is the parts which cause such movements—that is, the muscles—which make use of that energy. It is, perhaps, less obvious, but none the less true, that even such parts of an animal as liver and kidneys, which do not move about but which do chemical work of one kind or another, need energy for this. An ounce of the kidney needs as much energy as an ounce of heart muscle in spite of the fact that the latter is *apparently* working much harder.

Plants require much less energy than active animals but they need some, particularly in those parts which are growing and so working to build up new protoplasm. In short, it may be stated as a definite fact that *every living part of every living thing requires energy.*

Sources of Energy

There are various sources of energy which engineers can use to give them the motive power to run their engines. To-day, for example, increasing use is being made of waterfalls; the power which otherwise would run to waste being harnessed to drive dynamos and so supply energy for a wide range of industrial and domestic purposes. In other engines, again, the energy is derived from the burning of coal or the explosion of air mixed with petrol, oil or gas: here the real source of the power is the energy released in the chemical change which the fuel undergoes during combustion.

Apart from the direct use of sunlight in photosynthesis, living things can make use of only one source of energy—their

food. We have spoken in previous chapters of the use of food for energy (but we have also spoken of such foods as "bottled energy"). To release that energy the foods must undergo chemical changes and such *chemical changes carried out by living things to release energy are called "respiration".*[1]

Usually respiration involves *oxidation* of the food but, as we shall see in the case of yeast and certain other organisms, respiration need not necessarily involve the use of oxygen. Because of this distinction it is usual to describe the common type of respiration as *aerobic* (i.e. requiring air) and the respiration which does not require oxygen as *anaerobic* ("an" = not).

Aerobic Respiration

For this process we can write as an equation (but remembering that it is really much more complicated than this):

$$\text{Food} + \text{Oxygen} \rightarrow \text{Energy} + \text{Waste}.$$

In almost all cases the food used is a carbohydrate and the waste products are carbon dioxide and water. We can show that we produce carbon dioxide which is passed out of our bodies in breathing out, by blowing into lime-water. The clear liquid turns milky. The lime-water is a solution of calcium hydroxide in water and it reacts with carbon dioxide to form chalk—calcium carbonate—which appears as the milky precipitate. It is less easy to show that oxygen is used up but it can be proved for small animals such as worms and insects by an apparatus such as is shown in Fig. 95.

In the green parts of plants the exchange of oxygen and carbon dioxide due to respiration is normally much less during the day than the opposite exchange due to photosynthesis; but it is possible to demonstrate respiratory changes by conducting the experiment at night or in a dark chamber, or by taking parts of a plant that are not green. Germinating peas that have been soaked for 24 hours are usually used and after keeping some in a gas-jar for a few hours it can be shown that

[1] The meaning of the word respiration is often extended in common use to include "breathing", which is the taking in of oxygen and the giving out of carbon dioxide: biologists prefer to restrict the use of the word to the definition given above.

the gas remaining in the jar will no longer allow a taper to burn in it and will turn lime-water milky. Damp leaves, grass seedlings and similar green plants will give the same results if they are kept in the dark.

Some of the energy produced in respiration always appears in the form of heat. We know how hot we become when we run about energetically. By keeping damp germinating peas in a thermos flask and noting their temperatures we can prove

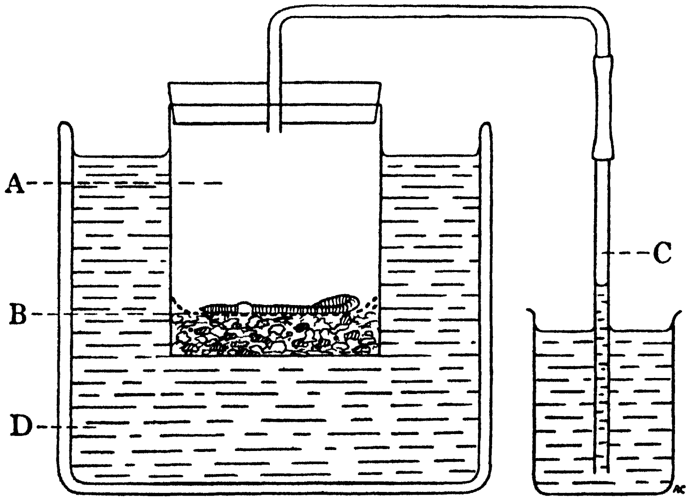


Fig. 95. Experiment to show that oxygen is used up in breathing. (For details, see Practical Work, § 2.)

that they too give out heat. About 75 per cent. of the energy released in respiration appears in the form of heat: only about 25 per cent. can be converted into actual work. This sounds as though the protoplasm were very inefficient in using energy, but really it is quite efficient when compared with a steam locomotive which can use only 12 to 15 per cent. of the energy available. Under normal conditions this heat is largely wasted but in so far as this waste heat may keep the temperature of

the organism above that of the surrounding air (and it very obviously does in "warm-blooded"[1] animals) it may hasten other chemical changes in the plant or animal. There is some evidence that this is important also in "cold-blooded"[1] animals and plants where the organisms are living at temperatures near freezing-point.

Anaerobic Respiration

Yeast is one of the smallest of all plants, each individual being a single, microscopically small, oval cell. It feeds sapro-

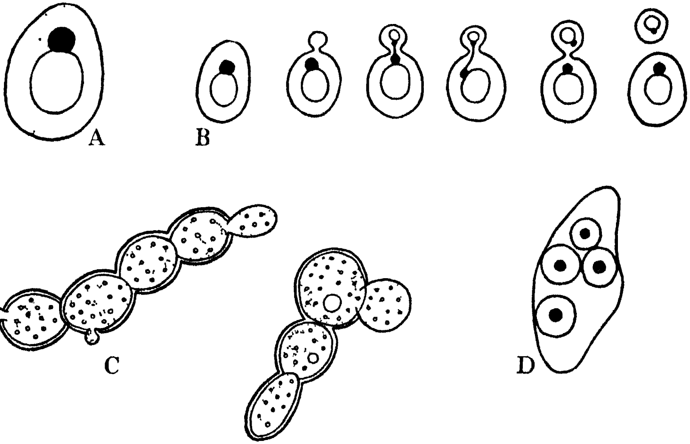


Fig. 96. Yeast. A, A single cell, showing cell wall, protoplasm, nucleus and vacuole. (×1000.) B, The process of budding. C, Chains of cells (nuclei omitted) formed by rapid budding. D, Formation of spores (this occurs when changing conditions make active life impossible).

phytically by taking in water with sugar and salts dissolved in it and using these things to provide energy and raw materials to build up new protoplasm in the making of *buds* which become new yeast cells.

[1] For definition, see p. 175.

When oxygen is available yeast can obtain energy by ordinary aerobic respiration:

Sugar + Oxygen → Energy + Water + Carbon dioxide.

When there is no oxygen available, however, it does not "suffocate" as we should, but can get energy from sugar by

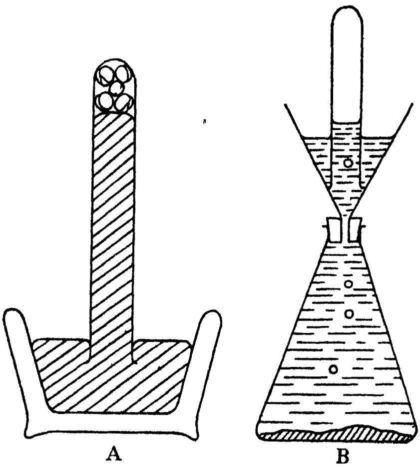


Fig. 97. Experiments on anaerobic respiration. A, Germinating peas over mercury. B, Yeast in a sugar solution.

another chemical change (which has come to be known as *fermentation* and which was studied by the great Pasteur):

Sugar → Energy + Alcohol + Carbon dioxide.

Since no oxygen is involved in this process it is also an example of anaerobic respiration.

Bakers and brewers make use of this change. Bakers mix yeast with their dough (in which it can obtain sugar but is cut off from the air). The carbon dioxide produced blows holes in the dough and so makes it rise, while the alcohol evaporates. Brewers start with a mash of malt (barley seeds which have been germinated and then killed by heat) in water: this contains dissolved sugar which is converted to the alcohol which

is present in beer, while the carbon dioxide bubbles to the top of the vat where it forms a froth.

Thus we see that this process of fermentation is a remarkably interesting one. The baker uses yeast for the sake of the carbon dioxide; the brewer is interested mainly in the alcohol but secondarily in the carbon dioxide which makes the beer sparkle;[1] while the yeast itself uses the energy that is liberated.

Most, perhaps all, other plants can carry out the same or similar changes for a short time. If you soak and skin some peas and then float them on the top of an inverted test-tube full of mercury and keep them in the dark you will find that they will produce carbon dioxide (and a smell of alcohol) although no oxygen is available.

That the processes of fermentation are less simple than we have indicated is shown by the ease with which, by means of it, glycerine can be obtained (instead of alcohol). During the first World War, the Germans made more than 1000 tons of glycerine per month by the aid of yeast.

Breathing

Since (for aerobic respiration) every part of a living thing requires oxygen, it is necessary that air should be able to enter from the outside and to circulate through the organism. Plants have a system of fine air spaces ramifying through almost every part, the air being taken in through the stomata of the green parts (p. 82) and through the lenticels of the bark. Plants which root in mud containing little or no air have specially large air spaces running from the parts which are exposed to air to the lower parts (e.g. stem of water-lily). Mangrove trees and the swamp cypress, which live under similar conditions, obtain air by sending up special structures like small ventilating shafts from the roots.

Insects have much the same arrangement—a system of fine branching *tracheal tubes* which take air direct to every part of the insect's body, penetrating even to individual cells lining the gut. In plants the gases move by diffusion, and so quite

[1] Carbon dioxide is often added artificially in bottling beer.

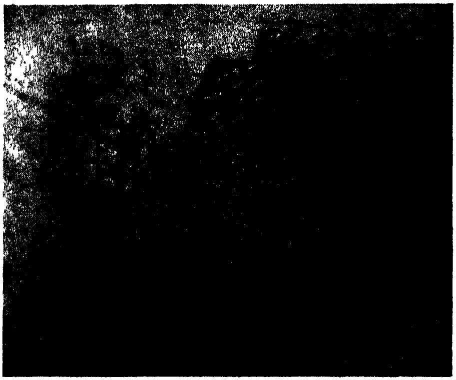


Fig. 98. Section of a lenticel of elder. (× 100.) Compare with Fig. 84. [Photo: J. H. Whyte.]

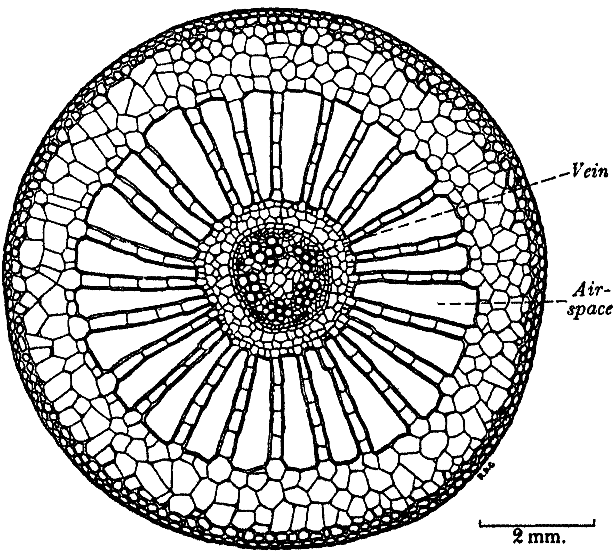


Fig. 99. Section across the stem of a Water Milfoil, to show the large air spaces typical of an aquatic stem.

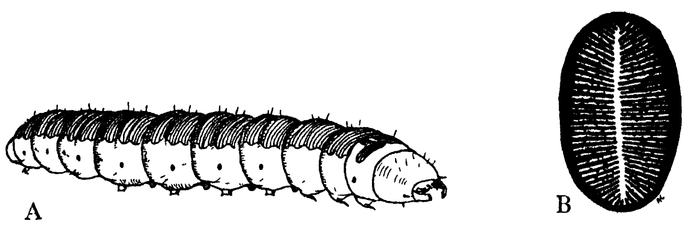


Fig. 100. A, A caterpillar: notice the *spiracles*—the openings of the air-passages—on the sides. B, A single spiracle—see under the microscope: notice the fine comb-like teeth which prevent dust from entering.

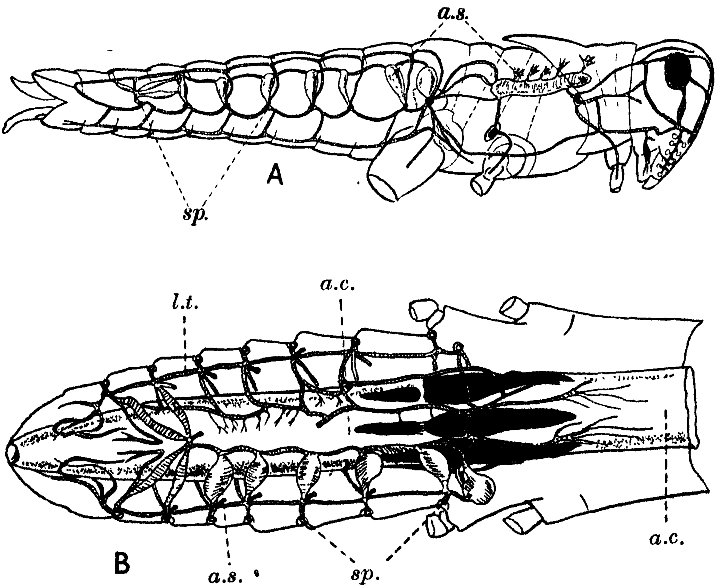


Fig. 101. Main *tracheae* in an insect (a locust). A, Side view. B, Back part of body, from above. *sp.* spiracles; *l.t.* a connecting trachea running along the side of the body; *a.s.* air sacs, which help in the circulation of the air within the body; *a.c.* food canal. [From Borradaile, *Invertebrata*, Cambridge University Press.]

slowly, but in insects the air in the tracheae is *pumped* in and out by movements of the body which can easily be seen in a wasp or dragon-fly. Such an arrangement is very efficient, and insects surpass all other invertebrates and many vertebrates in muscular activity, but it is efficient over short distances only —which is probably one of the reasons why all insects are comparatively small.

In practically all large animals the oxygen and carbon dioxide are carried round by the blood—the former by the

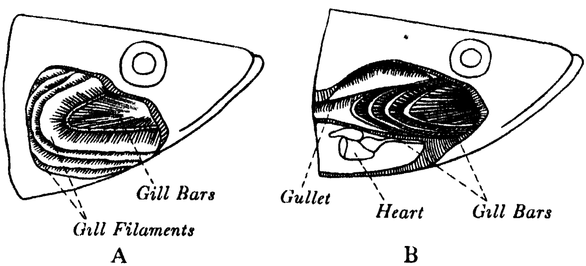


Fig. 102. Dissections of the head of a herring, to show the gills. A, The right gill cover removed. B, The right gills completely removed and the gill bars of the left gills seen at the side of the mouth. (The gill bars act as filters, preventing food particles from passing into the gill chambers.)

haemoglobin in the red corpuscles and the latter mainly dissolved in the liquid of the blood (p. 139). Hence there must be some part of the body where the blood can come into as close contact as possible with the air.

The taking of oxygen into the blood and the giving out of carbon dioxide take place most easily through a thin skin (of protoplasm) which covers a network of fine blood vessels. Such a skin must of course be kept moist or the protoplasm would die from lack of water. The outer skin of the frog, like that of the earthworm, is almost naked protoplasm kept moist by the secretion of its own glands. Consequently the frog can breathe through its skin, using it as a lung or (under water) as a gill. The amount of oxygen which can be taken in through such an area of skin is very inadequate and all large animals, in-

cluding the frog itself, need so much oxygen that they have very much larger surfaces for its intake. Such larger surfaces are provided by the finely divided filaments in the gills of a fish and by the tiny air sacs into which the air tubes of our own lungs branch. Although these air sacs are individually very minute, they are also very numerous, and their total area in the case of man is about 900 square feet—or nearly thirty times the area of the whole outer skin.

Breathing Mechanisms

In writing of the breathing of insects, we have mentioned the body movements which continually change the air in the tracheae. Similar *breathing mechanisms* are equally necessary in other animals. Fish use the oxygen dissolved in the water and keep a "one-way" flow of water passing in through their mouths and out through their gill openings. To do this they first open the mouth, lower the floor of the mouth and so take in water (the gill covers are so hinged that they close automatically while this takes place): then the mouth is closed, the floor of the mouth raised and the water thus forced out through the gills. Frogs force air into their lungs by a very similar mechanism but mammals use a suction method instead.

Our own lungs are two spongy bags hanging in the air-tight space of the thorax. The wind-pipe or *trachea*, by means of which air passes into the lungs, is strengthened by rings of cartilage (just as a garden hose or the hose of a vacuum cleaner is often armoured with steel wire) and divides at the bottom into two *bronchi*. Both trachea and bronchi are lined with cilia which all work together to drive any particles of dust, etc., back and up towards the throat. Within the lung each bronchus branches repeatedly (in the same way as the trunk of a tree branches to form the boughs and finally the twigs). The finest of the air tubes so formed have walls lined by tiny air sacs (*alveoli*) only a fraction of a millimetre in diameter. Around the very thin walls of these cluster a network of blood capillaries so dense that the spaces between them are even smaller than the capillaries themselves.

The sides and floor of the thorax are the rib muscles and the diaphragm respectively. The diaphragm is dome-shaped and on

contracting becomes flatter, while the ribs, which are roughly semicircular and normally droop from the breast-bone and backbone, force the sides of the thorax outwards when they are pulled up. Both of these actions increase the volume of the thorax and cause a partial vacuum there. Air is thus sucked down into the lungs (or perhaps it is better to say that it is

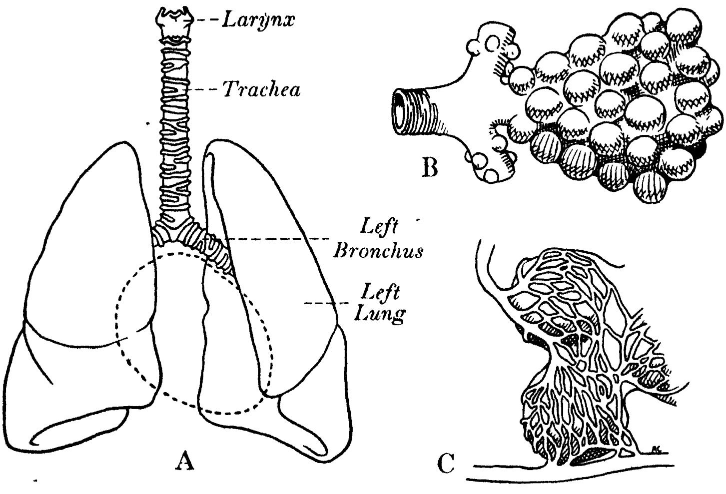
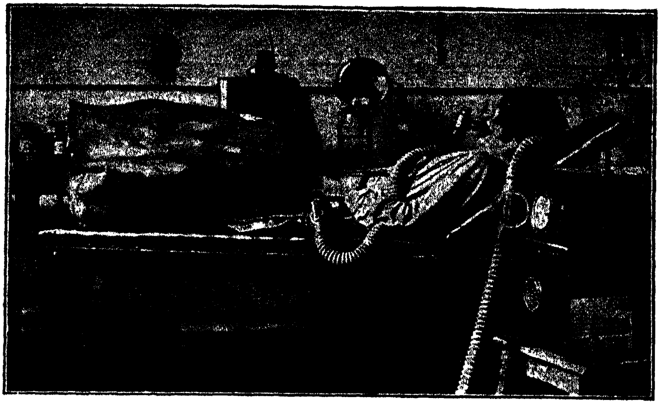


Fig. 108. A, The lungs as a whole (the position of the heart is dotted). B, A very small portion, highly magnified, to show the tiny air sacs where the gaseous exchange takes place. C, A part of B, still more highly magnified and with the capillaries shown.

forced into them by the pressure of the atmosphere operating via the nose, throat and trachea) and the lungs expand and fill the thorax. In applying artificial respiration to a man rescued from drowning, the operator attempts by rhythmic pressure on the back to make the ribs move as they would if the muscles were working actively.

The normal rate of breathing is about 14 to 18 per minute and, while by no means all the oxygen breathed in is used, the rate of breathing varies with the needs of the body. Thus a



A

B

Fig. 104. Experiments on oxygen consumption. A, Apparatus for measuring oxygen consumption of a girl at rest. B, Experiments on the oxygen consumption of a man wheeling bricks. [Photos: A. V. Hill.]

sleeping man uses about 220 c.c. of oxygen per minute while very strenuous exercise such as fast swimming may necessitate the use of over 2500 c.c. per minute.[1]

In an ordinary breath about 500 c.c. of air are taken in and breathed out, but in really deep breathing the full *vital capacity* of the lungs may be revealed as being seven or eight times as much as this. Some people take rapid and rather shallow breaths and consequently expand their lungs to only a slight extent: slower, deeper breathing, such as is characteristic of good athletes even at rest, is preferable since it keeps the whole of the lungs fit and ready for more strenuous use.

The amount of carbon dioxide in the blood controls the rate at which we breathe. When we begin to use our muscles actively they produce larger quantities of carbon dioxide and when, as a result of this, blood containing a larger amount of carbon dioxide than usual reaches that part of the brain which controls breathing, the rate of breathing is increased. Conversely, if we wish to hold the breath for a while, as in swimming under water, it will help if we take several deep breaths as a preliminary and so lower the amount of carbon dioxide in the lungs and blood.

PRACTICAL WORK

1. The production of carbon dioxide during the respiration of germinating peas, opening flower buds, pieces of a potato (or a complete potted green plant in the dark) can be shown by enclosing the material with a "sample" of air in a gas-jar (making certain that the cover-plate is airtight) or in a bell-jar standing in a trough of water. After a day or so, test with lime-water and a lighted taper. Small animals could also be used for this experiment.

2. That oxygen is used up in respiration can be demonstrated by the experiment shown in Fig. 95. The vessel, *A*, contains the animal or plant material in air or pure oxygen. Carbon dioxide produced is absorbed by the slaked lime under the wire gauze, *B*. Rise of water level in *C* will show that part of the air (actually the oxygen) is being used up. The water in the large vessel, *D*, should be kept at a constant temperature

[1] Compare the varying energy requirements discussed on p. 102.

and so prevent changes in volume in *A* due merely to changes in temperature. A layer of cotton-wool should be placed between the lime and the gauze.

3. Examine a thin smear of yeast, mixed with water, under the microscope. The fresh yeast-cake or baker's yeast may have few buds, i.e. growth is not active. To obtain actively budding yeast suspend a little of the fresh yeast in a 5 per cent. cane-sugar solution and keep warm (about 37° C.) for a few days, adding a little sugar (why?) from time to time. Brewer's yeast often shows the buds, or even chains of buds, better than baker's yeast.

4. Experiments on anaerobic respiration: see Fig. 97.

(*a*) Soak living peas for 24 hours and then skin them before putting them in the test-tube of mercury. After a few days test any gas evolved by blowing some caustic soda solution or lime-water into the test-tube by means of a pipette.

(*b*) Add a little fresh yeast to each of the following liquids and find out which yeast can use by observing from which of them carbon dioxide is evolved (notice also the smell of alcohol):

5 per cent. cane-sugar solution,

dilute treacle or honey (these contain glucose in fairly large proportions),

2 per cent. malt extract (which contains another sugar, maltose),

dilute starch "solution",

either olive oil or a suspension of olive oil in water (made by mixing the oil with a drop or two of alcohol and pouring the mixture into water),

a suspension of any protein in water (e.g. casein, prepared from milk, or uncooked white of egg).

5. Production of heat in respiration: thoroughly soak a couple of handfuls of peas. (It is best to buy peas sold for planting—the dried peas sold for cooking purposes are usually unsatisfactory for this experiment.) Divide into three equal lots. Place the first lot in a thermos flask. Boil the other two lots, one in pure water and the other in mercuric chloride solution (very poisonous!), and allow them to cool completely. Put these into two other thermos flasks. Into each flask put a little vial containing strong caustic potash solution—the vials can be held upright by means of a piece of cotton—this absorbs the carbon dioxide evolved and makes it possible to run the experiment longer than would be the case otherwise. Into each flask put a sensitive thermometer. Plug the mouths of the flasks tightly with cotton-wool. Read the thermometers several times a day for several days. Explain the results as far as possible.

6. Look for lenticels on bark of young and old twigs of horse-chestnut, birch and other plants. Look at microscopic preparations of sections of bark.

Look for air spaces in stem of water-lily leaves and flowers. Put one end of a cut water-lily stem in water and blow through the other. Try to blow through a woody twig of about the same size.

7. Examine an insect for breathing movements, and look for tracheae in a blow-fly larva held down on a slide under the lower power of a microscope.

8. Watch a goldfish or other small fish in a glass jar to observe its breathing mechanism. Examine the gills of a dead fish, crab, etc., preferably under water so that the gill filaments float free of one another.

9. Watch, under the microscope, the blood corpuscles moving through the gill filaments of a very young tadpole.

10. Study a set of "lights" obtained from a butcher's shop. Dissect a portion of a lung and try to make out some of the branching of the air tubes, and identify arteries and veins. The larger blood vessels around the air sacs can be seen quite well in the distended lung of a toad or frog: the capillaries can be seen in a portion of frog lung whose blood vessels have been injected and which has been mounted on a microscope slide.

11. Feel the movement of your ribs and the expansion of your chest in breathing. Close the mouth, pinch the nose, expand the chest and notice how strongly air is sucked down when the nose is released.

12. Breathe the same air in and out of a football bladder and notice how the depth and rate of your breathing automatically increases as the proportion of carbon dioxide in the air increases. Repeat with caustic soda solution in the bladder to absorb the carbon dioxide and compare the results with those of the previous experiment. (*In this case, use a pipette between the bladder and your lips so that you can avoid getting any of the caustic soda solution into your mouth.*)

13. Graduate a bell-jar in litres, measuring from the top downwards. Invert it, filled with water, in a sink; and, using a length of bunsen tubing as a delivery tube, measure the volume of an ordinary breath and your full "vital capacity". Compare these figures for different people. (A filter pump is very useful for sucking the air out of the bell-jar.)

CHAPTER X

WATER

Water and Life

There is every reason to suppose that the earliest living things were aquatic so that their protoplasm was continually bathed in water. It is a fact that all actively living protoplasm to-day contains a very large amount of water and that, even in plants and animals living on dry land, the actual protoplasm must be kept bathed in a watery solution.

We are careful—as we were in writing about the necessity for respiration—to say *actively* living protoplasm, for in some cases, where the protoplasm is almost completely inactive (as in seeds), we find that the amount of water is very much less. A study of the figures given in Chapter VI (p. 104) will confirm this. Notice the percentages of water in seeds (peas, nuts, etc.) and in foods derived directly from living organisms (meat, potatoes, etc.). Apparently the drying out of the protoplasm is a necessary condition for prolonged inactivity. Organs of vegetative reproduction (p. 221) such as bulbs and tubers, which have a high water content, will start growing when their season comes round: bulbs will grow even without planting, in the case of the onion and autumn crocus, while potatoes will sprout in spring even in a storage loft. It is evident that it is not lack of water which is responsible for the "rest" period in such cases.

Seeds, on the other hand, will not grow until they are given an adequate supply of water, and while it is *not* true that wheat from Egyptian tombs has been grown (most of it was killed by cooking before it was put into the tombs in any case!) it has been shown by actual experiment that seeds will "rest" and retain their powers of germination for many years. Thus Dr Beale started an experiment in America in 1879 with seeds packed in dry sand and buried in bottles. Some of the seeds from these bottles were still alive when removed about fifty years later (1927) and a small percentage grew when

planted. Mallow seeds have been grown after resting for ninety years while seeds of Indian lotus, which were certainly 160 and possibly 250 years old, germinated when planted under suitable conditions.

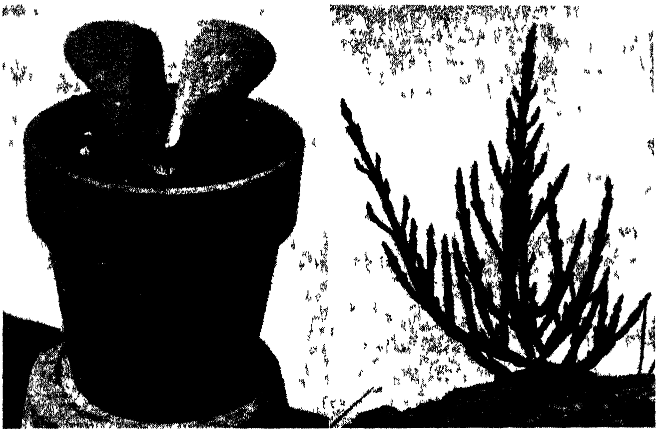
The spores of many of the simpler plants (and particularly those of bacteria) are capable of resting in a similar way and in this condition are extremely difficult to kill. They are capable of withstanding the temperature of liquid hydrogen (−252° C.) and of boiling water (100° C.). To be certain of killing them it is necessary to use water boiling under pressure —and so, as you probably know from your physics, boiling at a temperature well above 100° C. Here again, the ability to rest and to resist extremes of temperature is probably due to a very low percentage of water in the protoplasm.

Water Loss

If plants and animals living on land could wrap themselves up completely in a waterproof skin they would need only the little water necessary for making the materials used in growth. The plants which we call cacti (Fig. 31) and similar *succulents* (Fig. 105) which grow in situations where it is difficult to obtain supplies of water approach this ideal very closely, since their tough skins are almost completely waterproof. As a matter of fact the green parts of most land plants are covered with a waterproof, waxy layer or *cuticle* (perforated, of course, by the stomata) and woody plants have a waterproof bark covering everything but the leaves and finer roots. Most land animals, too, are covered with a fairly waterproof skin.

Even so, it is not possible to avoid loss of water since no plant or animal can wrap itself up completely and cut itself off entirely from its surroundings—there must be openings through which it can take in food and air. We have pointed out that the lungs in a land animal are lined with a protoplasmic skin and that this must be kept "soaking wet" if oxygen and carbon dioxide are to pass easily through it (p. 156). The air-passages of the nose, throat and windpipe are lined with a similar moist skin and as the air passes in and out in breathing, it is inevitable that some of this water should be lost by evaporation.

The evaporation of water from the lungs takes place rapidly in warm-blooded animals, for they warm the air which they breathe in and warm air can evaporate water much more easily than cold air. In cold weather the water vapour is condensed again after it is breathed out and so we can actually *see* the large amounts of water which are lost in this way.



A B

Fig 105. Xerophytic plants A, A desert plant from S. Africa, with only two succulent leaves (× ½). B, Glasswort (*Salicornia*), a succulent plant which grows on mud-flats (× ⅓). [Photos: R.D.G.]

In plants (as we have seen) the processes of respiration and of photosynthesis involve exchange of gases. Here, too, since the exchange takes place through a wet surface, there is an unavoidable loss of water. Such evaporation of water from plants is called *transpiration*, but, although the same word is not used, exactly the same thing happens from the skin of a worm or of a frog and from the lungs of a vertebrate. Plants are liable to wilt and dry up if they lose too much water; worms and frogs are equally liable to dry up and die if they stray from their holes or damp meadows on a hot, dry day.

Excretion and Water Loss

The organs of an animal do considerable amounts of work (far more than a plant does) and so produce large quantities of waste matter. These include carbon dioxide and water from the chemical changes by which energy is obtained, and a variety of other substances produced by the wear and tear of the protoplasm (e.g. ammonia— which is converted to urea by the liver—uric acid, etc.). Such substances must be removed from the neighbourhood of the protoplasm and if possible excreted, i.e. removed altogether from the body. Carbon dioxide is a gas and is easily removed by the process of breathing, but the other substances have to be excreted as solids or in solution. Since most of them are somewhat poisonous they must be passed out of the body *in dilute solution*. Such excretion, therefore, involves a considerable loss of water.

Some of the warm-blooded animals perspire through their sweat-glands and this involves a further loss of water, the significance of which we shall discuss in the next chapter.

Water Intake and Water Balance

It is essential that within fairly close limits the amount of water lost should be equalled by the amount of water gained. The danger of too great a loss of water—and it is a very real danger for plants and moist-skinned animals living on land—has already been stressed, but too great an *intake* of water can also upset the balance, though this may or may not be dangerous.

Since no terrestrial living thing can avoid loss of water it is obvious that both plants and animals must take in water to keep the amount within them constant. Plants normally take in the whole of their water supply through their roots while animals get theirs in their food and drink. In addition, water is formed in the chemical change of respiration (p. 149) and, in animals particularly, large quantities are produced in this way.

WATER BALANCE IN PLANTS

The loss of water by transpiration, inevitable since air must circulate through the stomata of the leaf and around the wet cell walls inside, may be quite considerable. A large white oak tree (an American species) may lose 150 gallons (about $14\frac{1}{2}$ cwt.) of water on a warm summer day so that you can imagine what enormous quantities of water are needed by large plants

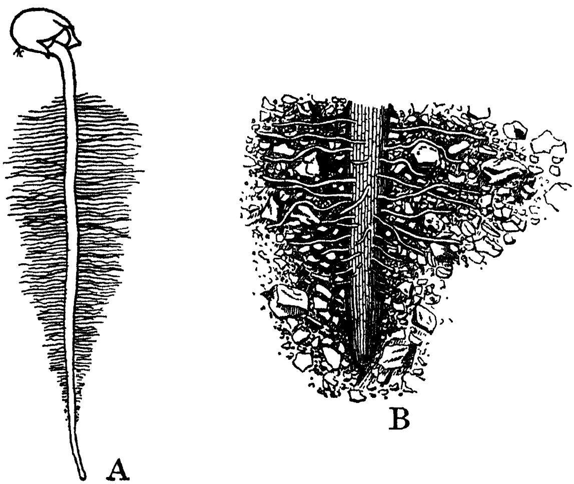


Fig. 106. Root-hairs. These grow just behind the tip of the root and are the actual parts of the root which take in water. A, Root-hairs as seen on a cress-seedling growing on the inside of a glass bottle. B, Diagram of root-hairs penetrating the soil. [B. From Fox.]

in the course of the summer. This water is taken in by the roots and a stream of water (the *transpiration stream*) is continuously moving up through the veins of the root and stem to those of the leaves. This current carries into the plant and up to the leaves the salts that are required in the building of more protoplasm. It is usually assumed—but it is by no means certain—that this upward movement of water is necessary for the carriage of the salts. It is therefore possible that

transpiration may be useful, but it is important to realise that it is certainly *an unavoidable danger* to the plant.

The first effect of too great a loss of water is that the plant has insufficient water left to maintain the turgidity of its soft parts (p. 34) and so these wilt. If the loss of water is soon made up the wilted parts do not die: thus on a hot summer

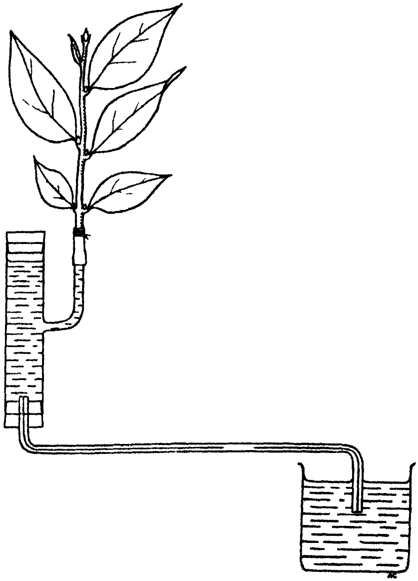


Fig. 107. Experiment on transpiration: clamp omitted. See Practical Work, § 7.

day, plants like beetroot, with large leaves spread out in the sun, may wilt for a while but recover during the following night when transpiration is lessened and the roots are able to make up the loss.

You may suggest that if the plant could close its stomata this wilting might be prevented. This is not completely true. Plants *do* close their stomata when suffering from a shortage of water but apparently there is still a slow loss—though

much less than would take place through open stomata. There can be little doubt, however, that this closure of the stomata is extremely important and that it does minimise the danger of wilting and further excessive loss of water.

Some plants store up water in large, juicy stems, some have hard, sharp needles instead of broad, flat leaves and so transpire very little, while others can roll up their leaves when they are losing too much water (e.g. marram-grass, p. 58) or have protoplasm which can stand a certain amount of drying out. Only such plants—they are known as *xerophytes*—can live in deserts (or upon roof-tops, e.g. house-leek and stonecrop) where the water supply is uncertain. The same is true of places where the conditions are such that it is difficult to take in water. Examples of such places are peat bogs where the soil water is so acid that the development of roots is poor; and coastal mud flats where the water is so salt that the roots cannot take it in by osmosis but must wait until *fresh* water—in the form of rain—is available (Fig. 105).

Fig. 108. A "Mist-maiden" growing 7000 ft. up in the Canadian Rockies. Note the drops of water forced out of the leaves on a damp day when evaporation was slow. [Photo: R.D.G.]

Plants under certain conditions—when the soil is well watered and the air is so cool and damp that little transpiration takes place—may take in more water than they lose, and in some cases this excess of water may be forced out of the special *water pores* of the leaf. This process of *guttation*, as it is called, is not unlike perspiration in animals in that in both cases water as liquid is forced out, but differs from transpiration since in the latter the water passes out as water vapour, and is carried away although the plant may still need it.

Water Balance in Animals

As we have pointed out, animals take in their supply of water in food and drink and lose water in the form of water vapour in breathing out, in the form of urine and (in many of the mammals) as perspiration. The loss in breathing takes place actually in the air passages of the nose, throat and windpipe before the air arrives in the lungs themselves, and the amount of water lost depends almost entirely on the temperature and humidity (dampness) of the air breathed in: the more water vapour it already contains the less "dryth" there is in it (to use a washing-day phrase) and the less water is lost by the body. The amount lost does not depend, therefore, on the amount taken in; nor does it in the case of perspiration, for the quantity lost in this latter way depends solely on the temperature of the body. Hence it is left to the kidneys to strike the balance. A large loss of water due to excessive perspiration or to breathing very dry air will cause an abnormally large thirst and so increase the amount of water taken in;[1] but whatever the intake or loss in other ways, it is the function of the kidneys to make certain that the total amount of water in the body does not vary appreciably. The brain does not add up the amount of water taken in, subtract the amount lost in breathing and perspiring and issue orders to the kidneys to excrete an amount of water equal to the balance! What happens is that an intake of water dilutes the blood and loss of water makes it more concentrated. The kidneys excrete enough water to keep the concentration, or strength, of the blood as nearly constant as possible.

Kidneys

There are two kidneys in all vertebrate animals and in us they are two dark red objects, about the same size as those of a sheep, fixed on to the back wall of the coelom in the "small of the back". Each has a large artery leading straight from the *aorta* (the main artery of the body) and a large vein going back to the *vena cava* (the main vein): hence there is a large, swift current of blood flowing through the kidneys. Within

[1] **A fireman in a ship's stokehold may perspire to such an extent that he needs to drink as much as 12 pints in a shift!**

them is an enormous number of small tubes, each of which is surrounded by a network of blood vessels and acts as a filter, taking out water together with the waste products and leaving the useful substances in the blood. All the tubes run into one another at their ends and the urine which they form drains away down two tubes known as *ureters* and is stored in the bladder until such time as it is convenient to expel it from the body altogether.

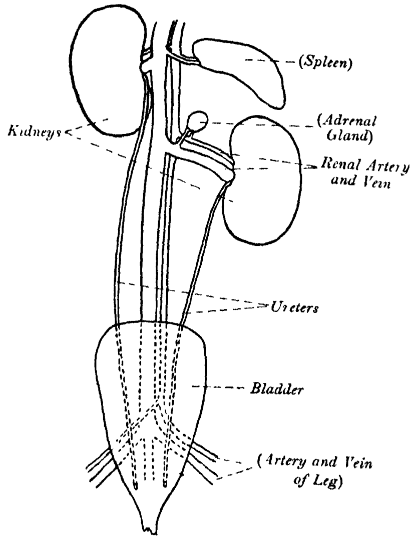


Fig. 109. The renal excretory organs of a rabbit.

Excretion in Animals

In addition to preserving the water balance in the animal body by excreting water, the kidneys (together with the lungs) keep the concentrations of the other substances in the blood constant. We have explained in Chapter VIII (p. 132) the necessity for the blood being kept at a constant strength and elsewhere (pp. 160 and 201) we point out how the rate of breathing is regulated in such a way that the amount of carbon dioxide in the blood is always the same. In the same way the

kidneys ensure that the amount of salt, urea, uric acid, etc. is kept constant. This involves not mere filtering but a *selective filtering*: the cells of the kidneys are continually taking one ingredient or another from the blood and excreting it in the urine and this is the *work* that is referred to in the previous chapter (p. 148). Of course, the waste products such as urea and uric acid are removed almost entirely—to such an extent that they are often far more concentrated in the urine than in the blood itself.

The salts—common salt and others—normally present in the blood are also excreted when their concentration is above normal, for it is as bad for the blood to contain too much salt as for it to contain too little (p. 133). Some salt is also lost in perspiration and carbon dioxide is expelled by the lungs: these, with the formation of urine by the kidneys, are the methods of excretion available to animals.

By excretion we understand the actual removal—usually from the blood—of waste products of the body's activity. The expulsion of undigested food from the intestines is not regarded as excretion, for this material has not been formed by the activity of any part of the body: on the contrary, it is material which the body cannot use. It is almost certain, however, that the walls of the large intestine excrete calcium phosphate, a substance which is so insoluble that it might clog the fine tubes of the kidneys. This, together with the bile which contains waste substances excreted from the liver, passes out of the body as part of the faeces.

Excretion in Plants

In the previous section we have been discussing excretion as found in animals. There is much less to be said about the same phenomenon in plants.

Waste products of respiration (carbon dioxide and water) and of photosynthesis (oxygen) are easily dealt with, but there are small amounts of other materials that must be got rid of in some way.

We have learnt that in animals urea is a prominent waste product. As a matter of fact urea also occurs in plants but it is not excreted in large amounts. On the contrary, in many of

the fungi urea accumulates until spore production (p. 224) and is then used up. There may, for example, be about 6 per cent. of urea in the dry matter of a mushroom, while in the case of some puff-balls there may be as much as 11 per cent. There is little doubt that here the urea is a food reserve (a form in which nitrogen may be stored) rather than a waste product.

Oxalic acid is supposed to be a waste product in many plants, and it may accumulate in considerable quantity. It is not removed from the plant, however, but is probably rendered harmless (for it is poisonous in large amounts) by combination with calcium to form insoluble (and hence harmless) calcium oxalate which may be seen as crystals in many plant cells. Large numbers of calcium oxalate crystals are often found in leaves which have fallen from deciduous trees and the dry material of some lichens may be two-thirds calcium oxalate.

Potassium and calcium salts are sometimes excreted, accumulating to a considerable extent on the outer surface of plants.

PRACTICAL WORK

1. Find roughly the water content of seeds and of other parts of living things—leaves, pieces of potato and onion, pieces of meat, etc.—by weighing them before and after drying at 100° C. in a steam-oven. (Weigh, heat for 24 hours, cool—in a desiccator, if possible—weigh. Reheat for 12 hours, cool and weigh again. Repeat if necessary, until weights are constant.)

2. Put some potatoes and onions aside on a shelf in spring and notice what happens to them. Place some dry seeds, and some seeds moistened with water, with them and compare the results.

3. Revise the practical work in Chapter v concerned with the structure of the leaf.

4. Compare the moist, clammy skins of worm and frog with the dry skins of insect and reptile.

5. Invert a jam-jar over a small glass vase containing flowers or leaves, standing in water. Pour a little olive oil or paraffin into the vase to prevent direct evaporation of the water. Set the experiment aside and notice how in a day or two water condenses on the inside of the jar and the level of the water in the vase goes down. (Control: set up a similar experiment, but without the flowers or leaves.)

6. The amount of water lost in transpiration by a potted plant can be found approximately by weighing it daily (the changes in weight due to respiration and photosynthesis are relatively small). It is necessary, of

course, to prevent evaporation of water from the pot or the soil: these should be completely enclosed in an aluminium shell or covered by tin-foil or some other waterproof material, after the soil has been well watered. Set up a control experiment for comparison, i.e. a similar pot containing a plant similar but decapitated and *completely* enclosed.

7. The way in which the transpiration rate varies under different conditions may best be studied by using a potometer, one form of which is shown in Fig. 107. The shoot should be cut from its parent plant, *under water* and the apparatus attached to it *under water*. When the shoot has had an hour or so to "settle down", raise the capillary tube from the beaker long enough to let a bubble of air enter. Measure the rate at which the bubble passes along the tube when the shoot is placed under different conditions—e.g. in warm or cold air, in dry or moist air, in still air or in a draught.

8. Take some nasturtium plants or barley seedlings and water them heavily. Place them in a shady place, preferably under a bell- or jam-jar, and examine them after several hours. Note the drops of water formed by guttation. Compare similar, but unwatered, seedlings.

9. Leave picked leaves (some of them completely covered by a thin coating of vaseline) in a dry place and notice how they lose water. Compare the rate of wilting of shoots of an ordinary plant, an aquatic plant (which has no cuticle) and a xerophytic plant. With a good letter-balance and using shoots of approximately equal size you should be able to compare quantitatively the loss of water by weighing from time to time.

10. Cobalt chloride paper, made by wetting filter paper with dilute cobalt chloride solution and drying it until it loses its pink colour, is very sensitive to water, turning pink again when it becomes damp. Carefully dry the surface of a leaf and place it between sheets of cobalt chloride paper held in place by dry pieces of glass. Notice which side of the leaf evaporates water more rapidly and compare your results with the remarks in Chapter v (p. 82) on the distribution of stomata.

11. A potato is covered by a layer of waterproof cork and an apple has a thick waterproof cuticle. To show how far these really do prevent loss of water, put two potatoes or two apples of about equal size, one peeled and one with skin, in a dry place. Weigh them at the beginning of the experiment and again from time to time: a letter-balance will do.

12. Examine a dissection of a rabbit or other mammal or of a frog and note kidneys, ureters and bladder.

13. Examine a prepared microscope slide of a longitudinal section of a kidney, preferably one in which the blood vessels have been injected.

14. Notice the salt taste of perspiration.

15. Remove a single kidney tube from an earthworm recently killed by immersion in alcohol and examine it under the microscope, noting the coils of the tube and the cilia within it, beating and so maintaining a current of urine along the tube.

CHAPTER XI

TEMPERATURE

"Cold-blooded" and "Warm-blooded"

Most living things, plant and animal, vary in temperature with their surroundings, being always approximately at the same temperature as the air or the water in which they live. Animals of which this is true are said to be *cold-blooded* but, while their blood (if any) is usually cooler than our own, that is not necessarily the case: the important thing is that their *internal temperature varies* enormously. The same thing is true of all plants: virtually, they are "cold-blooded" too.

Two classes of animals—birds and mammals—are *warm-blooded*: they have the power of *keeping their temperature constant* at a fairly high level, e.g. about 98° F. for man and most of the mammals and about 105° F. in the birds.

There are considerable advantages in being warm-blooded, for living things depend for their activity on the various vital processes which occur within them and the rate at which these processes take place increases very rapidly with a rise in temperature. As an example of the way in which the speed of vital processes depends on temperature, we may quote figures for the speed at which nerve messages travel:

Frog at 8° C. (46° F.)	53 feet per second.
Frog at 18° C. (65° F.)	95 ,, ,,
Frog at 37° C. (98° F.)	400 ,, ,,

In a "cold-blooded" animal a rise in body temperature of 10° C. usually doubles or more than doubles the rate of heart beat.

Again, the rate of development of eggs and seedlings is very considerably influenced by the temperature. In a recent experiment, records were made of the development of Canadian trout eggs kept in water at ordinary river temperatures (i.e. at about 2° C. from January to April and then

rising to 11° C. by the end of May). It was found that although the eggs were laid in October, the fish did not hatch until March and that it was May before they had used up all the yolk left in their yolk sacs.[1] (Fish normally have a fair amount of yolk left when they hatch.) Other eggs, laid at the same time, were kept in water at 10° C. These fish had hatched by the end of December and had used all their yolk by the end of January and consequently developed so much more rapidly that they were many times larger than the first set by the end of May—when our photograph was taken.

a

b

Fig. 110. Trout of the same age. The two smaller ones (*a*) developed in water at about 2° C. and the larger one (*b*) at 10° C. [Photo: R.D.G.]

In a world where life and death frequently depend upon quickness of action, it is not difficult to see from the above examples the advantage of having warm blood and so of being able to rely at all times on rapid nerve and muscle actions. It is not surprising, therefore, that birds and mammals are among the most successful groups of animals in the world to-day.

One disadvantage of being warm-blooded is that the production of the necessary heat within the body involves the using up (and therefore the obtaining) of much larger amounts of food than the cold-blooded animals need. Thus in the London Zoo the reptiles are usually fed about once a month but the birds and mammals are fed at least once a day. It is

[1] Compare Fig. 151.

not surprising, perhaps, to find that some normally warm-blooded animals (e.g. dormouse) become cold-blooded and hibernate during the winter in cold countries.

WINTER

In cold and temperate climates the vital processes of cold-blooded animals and plants are rapid enough in warm weather, but in winter they become very slow. Prof. A. V. Hill quotes the case of a tortoise (presumably in cold weather) whose biceps muscle took 30 seconds to contract. The tortoise is not noted for speed under the best conditions but, with muscle movements as slow as this, life is practically at a standstill. It is for this reason, principally, that most cold-blooded animals hibernate during the winter in all but tropical and semi-tropical countries.

In plants, also, the vital processes may be slowed down almost to a standstill in winter. We have already pointed out that the transport of food ceases at temperatures below about 6° C. (p. 138), and it is also true that the roots of the vast majority of plants can no longer take in water when they become very cold. This may place a plant in grave danger, for on a cold bright winter day the sunshine may be warm enough to cause the transpiration of more water than the roots can replace—a result which, if carried too far, would be fatal to the plant.

Plants can avoid the dangers of winter in various ways. Annual plants die completely at the end of the summer and only the seeds survive to give rise to new plants in the following season. In some perennials (p. 73) the aerial parts die down and only the underground parts—roots, bulbs, tubers, etc.—live through the winter.

Deciduous trees cut off their leaves in autumn. We say "cut off" deliberately for that accurately describes the process—and very interesting it is. The first thing that happens is that a layer across the base of each leaf stalk turns to cork and, since this is waterproof, the leaf can receive no further supply of water. The leaf dies and later (not till the following spring in the case of young beech trees) the layer just outside the cork layer crumbles and so the leaf is cut off. The layer which

breaks up is called the *abscission layer* (Latin *abscindere* = to cut off). The cork layer remains, of course, so we have the remarkable fact that the bandage (the cork layer) for the wound is already in place over the wound before it is exposed!

The leaves of evergreen trees have very thick, almost waterproof cuticle, and so manage to avoid any large amount of transpiration.

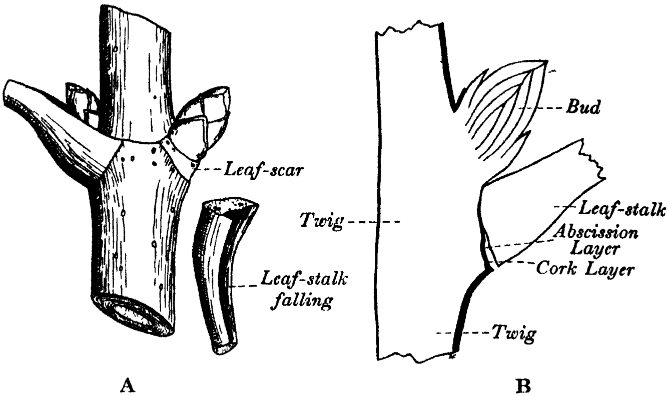


Fig. 111. Leaf-fall. A, As seen in sycamore. B, Section through the base of a leaf-stalk about to fall. [A, after Yapp.]

TEMPERATURE CONTROL

The way in which a high temperature is maintained by warm-blooded animals is very interesting. The outside temperature is usually lower than that of the animal and so heat is lost: thus at least an equal amount of heat must be produced and distributed throughout the body to make up for this. Actually more than sufficient heat is produced at times and a cooling system is then necessary.

Heat is lost mainly at the surface of the body and we find that almost all warm-blooded animals have a layer of hair, wool or feathers on their skin. The insulating (so-called "non-conducting") properties of these are due to the entangled air in each case and it is interesting to note that whereas the

flight feathers in the wing and tail of a bird are long and very smooth, the *down feathers* which retain the heat of the body are smaller but much more "fluffy".

Man has little of such protection but outside the tropics he keeps himself warm by clothes made from cotton, wool, silk and fur and by eiderdowns stuffed with feathers—in each case relying on the non-conducting layers of entangled air. Whales,

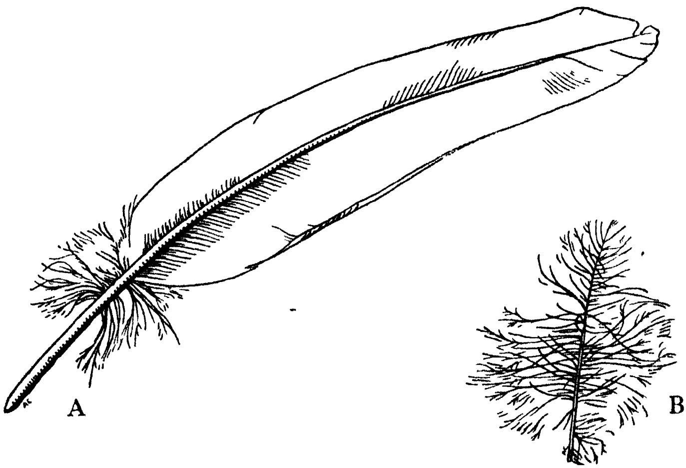


Fig. 112. The two main types of feathers.
A, Flight feather. B, Down feather.

seals and other aquatic mammals—and, to a lesser extent, man—rely on a thick, non-conducting layer of fat (blubber) immediately under the skin.

Even so, some heat is inevitably lost and this loss is compensated by the heat produced by the muscles and other parts of the body in respiration. We all know that we get hotter when we run about than when we keep still, but even when we are at rest our muscles are in a state of slight tension. To maintain this *tone* and to keep the heart, lungs, liver, kidneys, etc., working a certain minimum amount of respiration is always going on and consequently heat is always being made

to a greater or less extent. The figures quoted in Chapter VI for the energy used by the body and in Chapter IX for the amounts of oxygen used up in respiration will be almost exactly proportional to the amounts of heat produced.

The distribution of the heat which is necessary if the temperature of the body is to be the same throughout is one of the functions of the blood, which in this case acts in the same way as the hot water of a hot water system. It is warmed up in the muscles, etc. (i.e. where respiration is most active) and carries the heat to other parts.

For the temperature to remain constant the amount of heat made must be exactly equivalent to the amount of heat lost by cooling. During a race an athlete may make so much extra heat that his temperature rises two or three degrees. On the other hand, if we stand about in very cold weather, our heat loss may be so great that our temperature falls by a degree or two. The amount of heat produced must depend mainly on the *activity* of the animal concerned and the temperature cannot be kept constant by controlling the production of heat. The *loss*, however, can be controlled to a very large extent, in much the same way as the cooling is automatically controlled in certain makes of modern motor-cars.

When the body temperature rises, the arteries supplying blood to the surface capillaries of the skin open and flood the skin with blood. Consequently the skin becomes very red and, since the blood supply to the sweat glands is also increased, more perspiration is produced. The blood is cooled merely by coming to the surface but the cooling is greatly increased by the evaporation of the perspiration. The mere production of perspiration does not cool the skin at all: cooling results only when the perspiration evaporates (and to do that it requires large quantities of heat because of the high "latent heat of vaporisation" of water). Since the rate of evaporation depends on the dryness of the air we find it much easier to keep cool in a dry climate than in a damp one—105° F. in the shade is much more easily endured in the dry air of California than 90° F. in the damper air of England.

So efficient is this method of cooling that a man may stand in an oven long enough for a chop by his side to be cooked,

provided the air is dry. If the air is too damp, no perspiration can evaporate and no cooling take place: the temperature of the body then rises and, if it reaches 105° F., the heat-regulating centre in the brain ceases to function and "heat-stroke" results. This, and not suffocation, was the cause of the death of the 123 victims of the Black Hole of Calcutta.

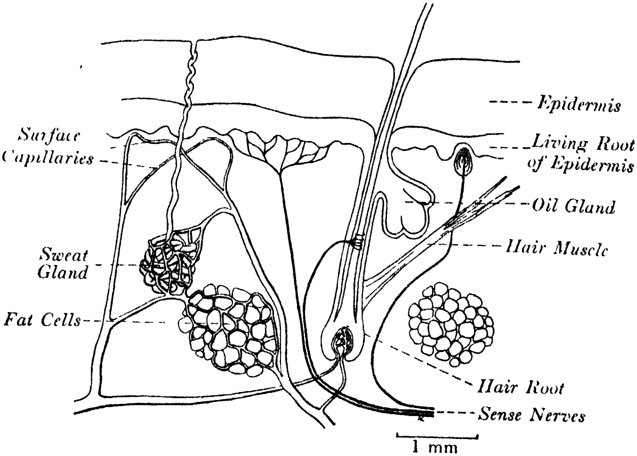


Fig. 113. The structure of the human skin: diagram of a section cut at right angles to the surface (highly magnified). The epidermis is composed of layer after layer of horny cells which are constantly being worn away at the surface and constantly renewed by the living "root" of the epidermis. Similarly the hairs are cylinders of dead cells and grow only from the roots—the same thing, again, is true of finger- and toe-nails. The average number of sweat glands is about 500 per square inch, but on the palms and soles there may be four to five times that number. Only some of the blood vessels are shown here—actually there is a dense network of surface capillaries under the epidermis—and the connective tissue which holds the various parts together is also omitted.

When the body temperature falls, the arteries carrying the blood to the skin close down partially or completely. In a person who is fit all blood leaves the skin and we say that the skin has gone blue with the cold. Also, in such a person the cold air will merely stimulate the body to make more heat, for it is a fact that the effect of cold air impinging on the skin is to

increase the tone of the resting muscles and so to increase their production of heat. This stimulation of heat production can work so well that a thoroughly fit person will take no harm even from standing naked and wet in a draught after a hot bath. In the case of a person who is not so healthy, some blood continues to run through the blood vessels of the skin even when he is very cold, but it quickly loses its oxygen and the skin therefore goes blue. For such a person, the stealing of heat by cold, damp winds may result in over-cooling and such lowered vitality that bacteria gain a hold and colds result.

GOOD AND BAD AIR

We all know that we feel tired and "heavy" in a stuffy atmosphere and in an attempt to find out how this happens the experiment shown in Fig. 114 was performed. The subject of the experiment lay on a couch in an observation chamber which was divided into two parts, *A* and *B*, by a fairly airtight curtain. In this way it was possible to give the man one sample of air to breathe and have another sample bathing the skin of his body.

Now the air of a stuffy room differs from pure "fresh air" in having a little less oxygen and a little more carbon dioxide and in being much damper owing to the evaporation of perspiration: also, it is usually warm and stagnant. When these conditions were produced and even exaggerated in *A* so that the man was breathing very foul air, he felt no discomfort provided that fresh air was circulated in *B*. When, however, he was given fresh air in *A* to breathe but *B* was filled with warm damp air, he felt all the discomfort of a stuffy room.

Quite obviously, the warm damp air bathing the skin would prevent the evaporation of perspiration and this experiment shows that it is that which helps to make a stuffy room unpleasant, and this is further proved by the fact that merely stirring up the air of a stuffy room with an electric fan will help to make it feel less unpleasant. We have already noted above that cold air on the skin stimulates the production of heat by the muscles and now we must add that variations in the coolness of the air around the skin appear to have a dis-

tinctly invigorating effect on the brain. This is probably quite as important as the evaporation of sweat, and explains the oppressiveness of hot thundery weather (the air is usually hot, stagnant and saturated with water vapour at such times) compared with the invigoration of a bright cold day in winter. Once we get used to it, cold air and cold water have a very considerable effect as physical and mental tonics.

Most of us to-day realise the importance of adequately ventilating our houses and public buildings and what we have

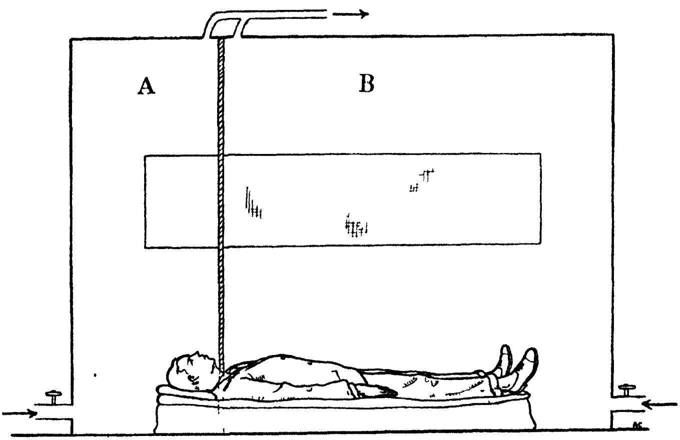


Fig. 114. Diagram of the experiment on "The Man in Two Rooms".

written in the last few paragraphs and what we shall have to add concerning disease bacteria in stuffy atmospheres (p. 266) explains the need for good ventilation. What is not so generally recognised is that it is the *skin* of our bodies rather than the lungs which needs the fresh air.

When we perspire freely the air around our skins quickly becomes saturated and if our clothes are fairly thick and air-tight (as men's clothes usually are) we carry our own "stuffy atmospheres" about with us. It is of little use ventilating our rooms unless we allow the air to circulate around our bodies. Hence the modern cult of light, loose clothing is one to be

praised and followed. In recent years, women have substituted this type of clothing for the far heavier and tighter clothing of previous generations—and they are certainly far healthier and more vigorous as a result of the change. Perhaps our generation will see the more conservative male evolve a new type of clothing acceptable on the grounds of health as well as of appearance. For the present, the general adoption of open shirts and shorts for sports is a step in the right direction—and we would add that such a costume may well be cooler in hot weather than a close-fitting woollen bathing costume. Light bed-clothes are also by far the best: an eiderdown is healthier than a heavy pile of blankets.

We scarcely need to stress in these days the importance of cleanliness of body and of frequent changes of underclothes. (Underclothes worn during the day should not be worn in bed also.)

Frequent hot baths are a help to attaining good health, for they wash away the salts and other substances which form part of the sweat but which do not evaporate. Sponging down with hot water or hot shower baths are equally good and are perhaps preferable in hot weather. Many people can stand cold baths (or a sponge-down with cold water after a hot bath) and benefit from the invigoration they give.

We have pointed out that exposure of the skin to cold fresh air tones up the muscles (p. 182) and the brain (p. 183), and we would add that such "air-bathing" can have a striking effect on health. This is well shown by results obtained in sanatoria situated in the high mountains of Switzerland. Here young boys and girls who are either suffering from tuberculosis in its early stages or have a disposition to that disease, live almost entirely in the open and, what is more, with a mere shred of clothing which leaves their bodies entirely exposed to the air both in summer and in winter. In the cold, clear, pure air of the Swiss mountains and with good food, adequate sleep and exercise, these children rapidly shake off the influence of disease and become extraordinarily healthy, happy and vigorous.

It is popularly supposed that such benefits are due mainly to the action of sunlight on the skin and as a result of this

sun-bathing and sunburnt skin have become very fashionable. Certainly a bright sunny day makes us feel much more cheerful than a dull day—and sunshine thus acts as a mental tonic—but apart from that, the action of the air is probably at least as important as that of the sun. Excessive sun-bathing, of course, can cause a most unpleasant and dangerous blistering of the skin.

PRACTICAL WORK

1. Divide a mass of frog spawn into two approximately equal lots and allow each lot to develop under the same conditions *except for temperature*. Keep one lot in a warm room and the other lot in a cold place and compare their development day by day.
2. Similarly, germinate seeds at different temperatures, giving them, apart from temperature, conditions as nearly identical as possible.
3. Examine as many wild and garden plants as you can in the winter and see how they are protected against the dangers of cold. Compare their winter condition with their condition in spring or summer.
4. Collect a number of leaves from different deciduous and evergreen trees, and notice the general differences between the two sets.
5. Examine deciduous trees which are in the process of shedding their leaves. Gently pull off some leaves and note the smooth leaf-scars, already covered with cork.
6. In early autumn, take twigs bearing leaves from a number of different deciduous trees and kill them by plunging them into boiling water for a few minutes. Leave them: are the leaves cut off?
7. Examine flight and down feathers of a bird.
8. Compare the heat-conducting properties of a number of garments or garment materials. Wrap a part of each specimen once (or twice) round a large test-tube (all the test-tubes must be the same size). Into each test-tube pour the same quantity of water heated to the same temperature. Place a thermometer in each tube and compare the rates of cooling under the same conditions. Find out whether the results are influenced by the tightness or looseness of the wrapping.
9. Take your temperature, by means of a clinical thermometer, when your body is under different conditions, e.g. after exposure to cold, on a hot day, before and immediately after a strenuous race.
10. Find out how the "thermostatic" control works in a motor-car radiator, and how the "Regulo" (temperature regulating) control works on a modern gas-oven.
11. Observe the close network of surface blood vessels in the skin of a rabbit's ear on a hot day (or when the rabbit is warm in front of a fire). Take the animal into a cool place: what is the effect?

12. Pour on to your hand a few drops of ether or other volatile liquid. Allow it to evaporate and notice the cooling which results.

13. Read a thermometer and cover its bulb with a wet cloth: read the thermometer again in a few minutes. Compare the effects obtained in still air and in a draught. Find out how a "wet-and-dry thermometer" is used for the measurement of humidity.

14. Watch an ant-hill on a day when periods of warm sunshine alternate with periods when the sun is obscured by clouds—and notice what a difference variations in temperature make to the speed at which ants move about.

CHAPTER XII

CO-ORDINATION AND BEHAVIOUR

So far in this book we have been discussing the various organs in living things, and the different life processes which they carry on, almost as though they were quite separate and independent of one another. Certainly it is true (p. 31) that such organs, and even the cells of which they are composed, can in many cases be kept alive and functioning as independent units. We must not, however, lose sight of the fact that the various organs are merely parts of the whole organism and that the latter has a life of its own. For this life to be carried on successfully the parts must work in harmony with one another and the life processes must be *co-ordinated.*

CO-ORDINATION

We have already mentioned many examples of this, e.g. the way in which the blood supply to various parts of the body is regulated according to the needs of those parts (p. 145), the fact that the number of seeds or buds which develop is related to the amount of food available and the co-ordination of the various ways in which heat is made and lost in warm-blooded animals so that the temperature remains constant (p. 180). Again, running, walking, jumping, and similar movements each involve the careful co-ordination of a large number of muscle actions—even a smile is said to involve over sixty muscles! In growth and development, co-ordination is essential: in a developing embryo, the parts must grow in proportion to one another or all kinds of queer results would follow. We know too that developing fruits grow but do not normally ripen in colour or taste until the seeds within are ripe and are ready to be scattered. Obvious exceptions are seedless oranges, bananas, etc.

(*a*)

(*b*)

Fig. 115. Growth-movement in a water-hyacinth. The movement results in the developing fruits being pushed under water and it normally occurs after pollination. It was formerly thought that the movement was caused by the stimulus of pollination (see earlier editions of this book). One of us has recently found by experiment, however, that the movement takes place even if all the flowers are removed from the stalk before there is any possibility of their being pollinated—another example of the advance of scientific knowledge. [Photos: R.D.G.]

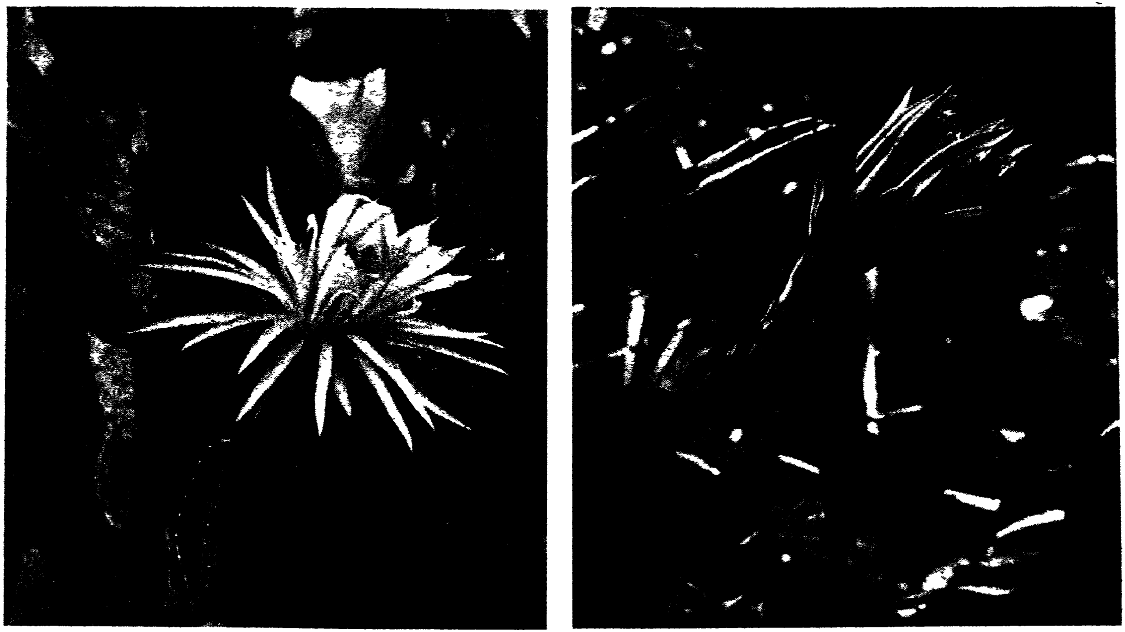
Irritability

In addition to the co-ordination of the various parts and processes within a plant or an animal, it is also necessary that the organism should regulate its behaviour in relation to the changes which take place in the environment around it. There are many factors in the environment which influence living organisms. The lives of plants, for example, are influenced by (among other things) sunlight, by the temperature, by the supply of water in the soil, the speed of the wind and the dampness of the air. Animals are similarly influenced by a whole range of factors, chief among which are the abundance and accessibility of food and drink and the presence of enemies.

Now these factors in the environment are continually changing and if the organism is to survive it must be constantly adjusting itself to such changes, behaving in such a way that it does the best it can in varying circumstances. However well a plant's or an animal's parts are working together, its life would soon be cut short if it failed to behave in proper relation to the things that are going on around it, i.e. to the changes in its environment. Thus a mouse may be quietly nibbling cheese when it sees or hears a cat. The approach of the cat will be a "change in its environment" and will stimulate the mouse to instant action. Such an action is called a *response to a stimulus* or a *reaction to a stimulus. The ability to respond to stimuli is possessed to some extent by all living things and is spoken of as "irritability".*

Amoeba shows this power of responding to stimuli when it engulfs a food particle or moves away from the pricking of a fine glass needle: the presence of the food particle and the pricking are the *stimuli* and the movements are the corresponding *responses.* Many flowers open only when light falls on them, and correspondingly a decrease in intensity of light stimulates the closure of such flowers[1] and of a number of leaves. That these "sleep movements" are not merely rhythmic but are true responses to stimuli is shown by the fact that they occur during an eclipse of the sun. Such examples could

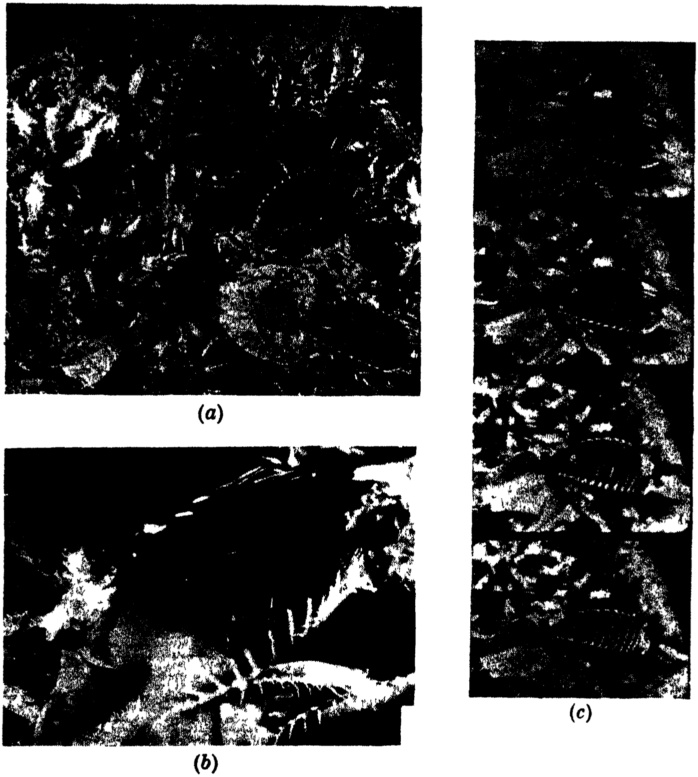
[1] The reverse is true of night-flowering plants (Fig. 116).



A B

Fig. 116. The closing of a night-flowering Cactus, eleven inches across. A, 10 a.m.: the flower is just beginning to close. B, Three hours later. [Photos: R.D.G.]

be multiplied almost indefinitely but we will leave you to think out others for yourselves. Meanwhile we would point out that,



(a) (b) (c)

Fig. 117. Response to stimulus in the Venus fly-trap. *a*, Part of plant (about natural size). Note the traps—three are open and one is closed. Each is the top portion of a leaf, the lower part of which carries on photosynthesis. *b*, The trap of a single leaf: note the six "trigger" hairs (× 4). *c*, The trap in action: four pictures from a cinema film, taken at intervals of about ¼ second. [Photos: F. E. Lloyd.]

while irritability is a characteristic of all living things, we cannot say, in these days of actuated traffic lights, photo-

electric cells and other almost human pieces of machinery, that responses to stimuli are found *only* in living organisms. What we can say of living things is that they respond to stimuli in such a way that they enhance their own welfare—or, as in the case of parent animals making sacrifices for their young, the welfare of the race.

We must note also that the co-ordination which we considered in the previous section is really very much the same as the irritability we are considering now. They both depend on responses to stimuli and the only real difference is that the responses in cases of co-ordination of the parts of the organism depend on stimuli which arise *within* the organism itself and not outside it (e.g. our muscles shiver when stimulated by a lowering of the temperature within the body).

BEHAVIOUR

We all know roughly what we mean by behaviour and we might define it as the sum total of all the actions of a living organism—or, since practically all its actions are responses to stimuli, we may say that behaviour is the sum total of all the responses to stimuli, whether these arise from without or within.

Behaviour in Plants

It may perhaps seem odd to speak of plants "behaving" at all, but, as we have seen in Chapter IV and earlier in the present chapter, they certainly respond to stimuli and the sum total of all they do in the way of responding will be their behaviour. An animal needs to act rapidly if it is to capture food and escape from enemies, but a plant, with its needs limited to air and sunlight, and water and salts from the soil, usually has no need of rapid movement. Its activities are almost wholly directed towards attaining the best position for its various organs. This can be achieved quite well through the slow agency of growth.

We find that there are three main factors which influence the growth of root and stem. As we might perhaps expect, two of these factors are water in the case of roots, and light in

the case of the stem (since the stem bears the leaves). We find that roots tend to grow towards a supply of water and that stems tend to grow towards light. Such growth tendencies are called *tropisms* or *tropic responses* (Gk. *tropos*, a turning).

In addition, since light is normally found above the soil and water below, we shall not be surprised to find that, other

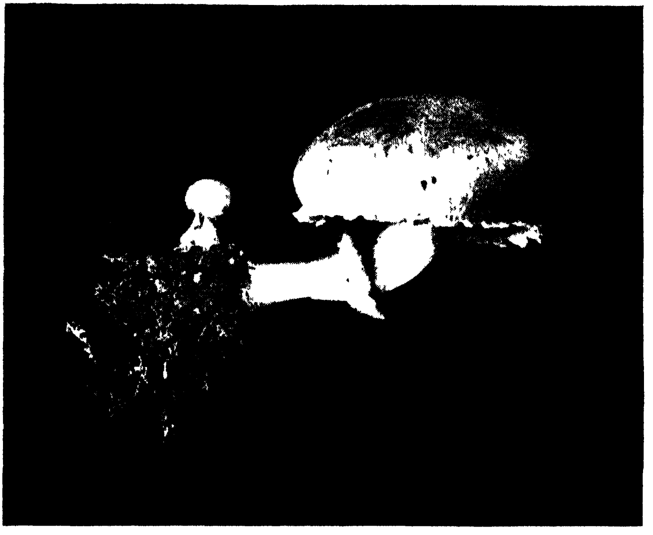


Fig. 118*a*. The ordinary mushroom is extremely sensitive to the force of gravity. (Buller has shown that the gills of a ripe mushroom are normally less than 1° from vertical!) In the experiment illustrated above, the mushroom was placed horizontally instead of vertically in a clamp: within 48 hours the stalk had grown in such a way as to bring the gills back to vertical again. [Photo: R.D.G.]

things being equal, stems and roots respond to gravity: stems tend to grow upwards and roots tend to grow downwards and, in some cases at least, away from light. Obviously this is true only of main stems and main roots: branches of both often grow horizontally.

You will be able to demonstrate the response of the stem to gravity if you grow seedlings in complete darkness (when light can obviously have no effect at all). If, on the other hand, you have seedlings or the stems of a well-developed plant with light falling on them mainly from one side the stems will bend and grow towards that light: this fact is well known to anyone who has grown plants in a window.

Similarly, roots, which have an adequate supply of water all round them, will grow directly downwards, while in a drier soil the roots, and particularly the branch roots, will grow towards any specially moist regions.

A comparison of seedlings of the same species grown in darkness and in daylight demonstrates certain other responses to light on the part of the stem. The stems of the plants grown in the light grow more slowly but grow thicker and stronger, while their leaves develop fully. In addition, the green substance chlorophyll is formed only in the stems and leaves exposed to the light—as you probably know, we "earth up" potatoes and celery to keep them white. Seedlings grown in darkness form long, thin, spindly stems without

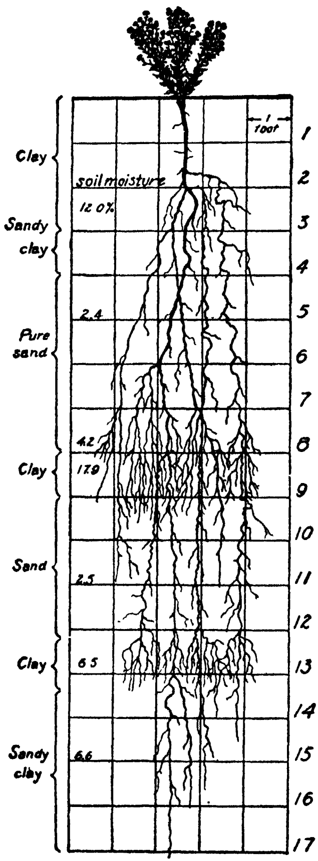


Fig. 118*b*. Root-system of an American prairie plant growing in alternate layers of clay and sand. Notice that the number of branch roots in the various layers is correlated with the water-content. [Weaver.]

chlorophyll and with only very small, useless leaves—they are said to be "etiolated".

These are the main elements in any plant's behaviour. Certain plants show other responses in addition: we have illustrated one of these in Fig. 117 and mentioned others in Chapter IV (p. 57).

Automatic Actions in Animals

The behaviour of plants is purely automatic: the same response always follows the same stimulus. In most animals we find much the same type of purely automatic behaviour—animals may be ruled in their activities as slavishly as plants are—though many of them can modify their behaviour as a result of experience or by the use of reason.

As an example of purely automatic behaviour we may cite the case of moths flying towards a light at night. This seems to be due to the fact that each eye controls the wing (and leg) muscles of the opposite side. If a moth in flying has a light on its left side, more light falls on the left eye than on the right and, as a quite automatic consequence, the muscles of the right side work more strongly than those on the left and the moth flies or walks towards the left. That this explanation is true is suggested by two facts. If one eye of a moth is covered with black paint and the moth let loose in daylight it walks or flies round in circles with the painted eye on the outside of the circle. Again, a moth in the presence of two lights, equally bright, usually flies not to either one of them but in a direction that leads half-way between them.

Any animal will furnish us with plenty of examples of automatic actions. We sneeze automatically when anything irritates the mucous membrane lining the nose, we cough when "a crumb goes the wrong way" and lodges in the larynx, and we blink when anything comes rapidly towards our eyes.[1] These are relatively simple examples but there are many cases where complicated *sets* of responses are involved. We have already mentioned that a smile involves the co-ordination of over sixty face muscles, so that if you laugh when you are

[1] **We can control such automatic actions to *some* extent, but not by any means completely.**

tickled the response concerned is by no means simple. The act of balancing is one of the most complicated automatic actions in the human body, for it involves the constant adjustment of the muscles not only of the legs but of those of vertebrae as well.

Many automatic responses are actually inborn and are thus as truly a part of the heredity as the actual arrangement of the organs in the body. Such inherited responses are called *reflex actions*. Most of the examples of automatic responses which we have given so far in this section are inborn and are thus reflex actions. As a further example, we may quote an experiment by Lloyd Morgan who, in America, hatched some moor-hen eggs in an incubator and as soon as the young moor-hens emerged—before their down was properly dry and before they could walk with much steadiness—gently lowered them into a bath of water. Although the young birds had never seen water before and certainly had never seen any other birds swimming, they immediately swam with fair ease.

Not all the reflex actions in such an animal's "répertoire" develop at once. Thus Lloyd Morgan found that he could not get his young moor-hens to dive at first, but when the birds were nine weeks old he saw one of them dive perfectly at the first attempt—again without having seen any other bird perform the action.

Learning by Experience

Many animals can learn from their experience. In many cases, this involves the modification (*conditioning* is the biological term) of inherited reflex actions. For example, the watering of the mouth when food is *tasted* is an inborn reflex action, which is gradually modified by our experience of what good food looks like so that in time our mouths water when we see, or smell or even think about, food (see Fig. 128).

New items of behaviour learned from experience are not necessarily connected with inborn reflex actions as the following experiment shows. The investigator made a **Y**-shaped tube and in the top right-hand side fixed wires which could be connected to an induction coil. A worm was put into the opening at the bottom of the tube and when it had crawled

along the stem it had to choose between turning to the left or to the right. The experiment was repeated time after time with the same worm and at first – without the electric current on—the worm turned as often to the right as to the left. When the current was connected, the worm received an electric shock each time it turned to the right and gradually it learned to go to the left each time. These are examples of the formation of *habits*.

Reasoned Actions

Some of the mammals, including man, are capable of more than mere automatic actions. They are capable of "thinking things out", and so show powers of reasoning. We can see the difference in the ways in which different animals tackle problems.

We all know Aesop's fable of the fox which saw grapes on a vine over his head and merely jumped up towards them again and again. A monkey was given a similar problem to solve: a bunch of bananas was hung from the roof of his cage. The monkey quickly realised that they were out of his reach and then took some boxes which were in the corner of his cage and piled them up under the bananas until he could reach the bananas by climbing on the boxes and using a stick. The monkey's use of the boxes was not accidental but deliberate: he quite definitely *thought out* a plan for obtaining the bananas and showed that he *foresaw* what might happen if he used the boxes.

Of course, a problem may be solved without the use of reason. Thus a dog, wishing to enter a garden, may jump repeatedly against the fence and gate until, quite accidentally, he jumps on to the latch of the gate and so is able to enter. (He may remember the experience and so form a *habit* of entering in such a way.) This would be a purely accidental solving of the problem. It is the method of trial and error—a method which requires no thinking or foresight.

Animal Behaviour

Except for the few which show the capacity for reason, the behaviour of animals is purely automatic, consisting very largely of numbers of reflex actions. Such behaviour is called

Fig. 119. An example of intelligence in a monkey. [Bierens de Haan.]

instinctive behaviour and probably reaches its highest development in insects and birds.

Instinctive behaviour can be amazingly perfect and does not require to be learned—but its disadvantage is that it cannot easily be altered to meet changing circumstances.[1] Reasoned behaviour on the other hand can be altered to meet altered circumstances—an enormous advantage in a world where the conditions of life often change considerably.

Even in animals which have the capacity for reasoning, a very large part of the total behaviour is still automatic; and it is well that this should be so. Life would be impossible if we had to reason out every single action, to think out every muscle movement in walking, breathing, chewing and the hundred and one other actions which now go on without our having to think them out each time.

In addition to purely instinctive behaviour and reasoned behaviour there is, of course, the power of forming habits by frequent repetition. The higher the animal in the evolutionary scale, the more easily does it form new habits—though it does not necessarily think about them. Both reflex actions and habits are automatic: they differ in that habits form no part of the inheritance. Once habits have been formed, it is very difficult to alter them. We have already pointed this out in speaking of style in athletics (p. 69). Here we would merely add that habits are, like reflex actions, extremely useful servants, but if we allow mere habits (e.g. excessive smoking) to master us they may become very bad masters.

PRACTICAL WORK

1. Notice the positions of the tip of a climbing stem of bindweed at intervals of half an hour and of the young tendrils of a sweet pea from day to day.

2. Put a clover or wood-sorrel plant into complete darkness and look at it after an hour or so. Shade flowers of the scarlet pimpernel which have been in bright sunlight and notice the result.

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[1] A good example of the lack of adaptability was observed by one of us recently in his garden. A mason-wasp carefully built a cell on a piece of Purbeck stone, using mud collected from the edge of a lily pool. When dry the cell matched the stone almost perfectly but the wasp then proceeded to "camouflage" it with tiny pieces of gravel with the result that it became far more conspicuous than before.

3. Put a small potted plant or a vase of sunflowers in a window, or a saucer containing young mustard or cress seedlings in a box illuminated only from one end. Compare the behaviour of these plants with that of similar specimens illuminated equally from all sides.

4. Germinate some seeds in complete darkness and compare them with others, germinated in the light but under otherwise identical conditions. Notice particularly the growth of the stem and leaves and the behaviour of the tip of the stem. In this way you can determine the responses of the seedling to light.

5. Study the behaviour of the parts of a plant in relation to gravity. Broad-bean plants are very suitable for such experiments as these.

(*a*) Germinate some seeds in a jam-jar lined with damp blotting paper, placing some seeds up one way and others up the other way. Notice the directions in which the roots and shoots grow: does the position of the seed make any difference?

(*b*) Take a potted plant about five inches high and place the pot on its side: look at it again after a few hours and, after a day or two, put the plant upright again.

(*c*) Try to repeat the experiment shown in Fig. 118*a*. Do other fungi behave in the same way?

(These experiments should be performed in the darkness so that the results are not influenced by responses to light.)

6. The response of the root to moisture can be shown by the following experiments.

(*a*) Replace the bottom of a shallow wooden box by fine wire or string netting. Fill it with damp moss, plant some peas in it and keep the moss damp. Hang the box in a dark cupboard with one side higher than the other. Notice what happens when the roots of the germinating peas grow down through the netting.

(*b*) Plant some bean seedlings at one end of a box which is filled with dry sawdust, except for some damp moss at the other end. Add a little water to the moss (but not to the sawdust) daily and watch the behaviour of the roots.

7. Make careful observations on the behaviour of insects and of young animals such as puppies or chickens. Try and find out how far the details of their behaviour are automatic, and whether they show any signs of thinking out problems *which they meet for the first time*, e.g. maroon several ants on a brick in a large dish of water: provide bridges.

8. Feed goldfish or other small fish in an aquarium always at one particular corner, tapping the glass before each meal. After a time, the fish will learn from their experience and the mere tapping of the glass will result in a gathering of fish at the corner.

CHAPTER XIII

THE MECHANISM OF BEHAVIOUR

There are two methods by which responses to stimuli are achieved in living things—by chemical substances and by the nervous system. To illustrate these two methods we might consider what happens when we start to make vigorous use of any of our muscles.

When a muscle is at rest only about one-sixth of its capillaries are open at all: the remainder are kept closed by the slight alkalinity of the blood and also probably by the presence of oxygen. When the muscle begins to work it increases its production of carbon dioxide and later its consumption of oxygen (p. 66)—as much as fiftyfold. The first effect is that the increased amount of carbon dioxide poured into the blood makes it acid. This in turn results in the opening of the closed capillaries: those that were open expand even more. Thus the muscle obtains a greatly increased flow of blood by means of a very simple piece of *chemical control.*

In addition, of course, the active muscle will need much more oxygen and in order that this may be supplied it is necessary for the breathing to become deeper and more rapid. We all know that this takes place, and the mechanism involved is as follows. When the blood containing more carbon dioxide than usual reaches that part of the brain which controls the breathing rate, messages are sent along certain nerves to the rib muscles and diaphragm so that deeper and more rapid breathing results. Here then, control is exercised by a mechanism involving both a chemical and *the nervous system.* By a similar mechanism the rate and strength of the heart beat is increased.

We shall now proceed to examine these two types of mechanism in greater detail.

CHEMICAL CONTROL: HORMONES

We have pointed out how the amount of carbon dioxide in the blood controls the opening of the capillaries and the rate of breathing. Now carbon dioxide is not a chêmical substance made specially for such control, but there are many such specially made chemicals or *hormones*, formed in the body by glands which we call *ductless glands* or *endocrine organs.*

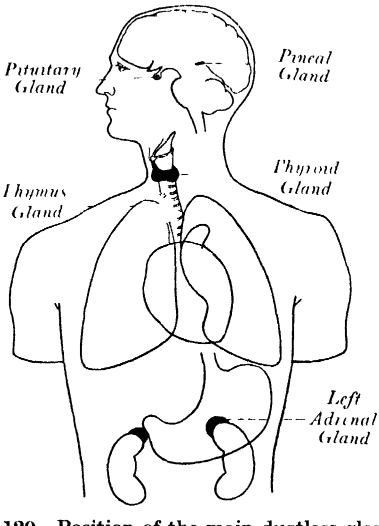


Fig. 120. Position of the main ductless glands.

Hormones are important mainly for controlling the internal co-ordination of the organism, for controlling growth and development and for carrying out responses where, as is often the case in plants, such responses need not be very rapid.

We may take *adrenalin*, made by the adrenal glands (found just above the kidneys) as our first example of a hormone. Its special function is to mobilise the resources of the body in an emergency, e.g. in a fight, or when we are excited about running a race. To do this, it speeds up the heart and dilates the capillaries, stimulates the sweat glands so that the body

may be cooled, slows the movements of the food canal and contracts its blood vessels (digestion can wait in an emergency), makes the liver release some of its stored glycogen so that the muscles have plenty of food, stands the hair on end, dilates the pupil, and makes the eyeballs bulge—a wonderful range of results and one which gives us another good example of co-ordination.

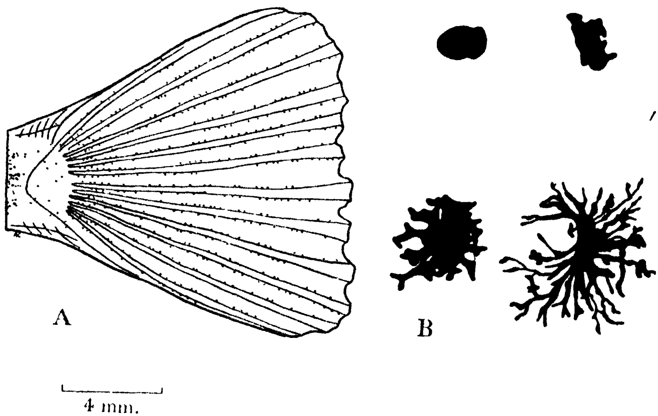


Fig. 121. Colour spots. A, Spots in the tail of a stickleback. B, Four drawings to show the expansion of a single spot (after L. T. Hogben).

The mechanism of colour change in such animals as frogs, prawns and sticklebacks is another example of a hormone playing a part in carrying out responses to external stimuli. If, for example, a frog is kept in a dark place with plenty of water its skin becomes a very dark green, whereas in dry, light surroundings the frog turns a quite pale yellowish green. The colour change is caused by special pigment cells which are found in the skin and in which the black pigment spots can be contracted or very much expanded—making the frog light or dark respectively.[1] The expansion is controlled by a hor-

[1] In the Aesop prawn, there are *three* sets of such spots—one set red, another yellow and the third blue. With these the prawn can change its colour to match almost any background: see Russell and Yonge, *The Seas*, pp. 180–2.

A

B

Fig. 122. Colour changes in animals. A, Colour change in prawns as a response to change in environment: the one prawn had been on a light and the other on a dark background for half an hour.
[Photo: E. M Stephenson.]
B, Colour change in frogs as a result of hormone injection. Both frogs were kept in dry light surroundings, but the one on the right was treated with pituitary hormone. [Photo: L. T. Hogben.]

mone from the pituitary gland (situated at the base of the brain) and the production of the hormone is in turn controlled by nerve messages from the eyes. Thus, when a frog is in dry, light surroundings messages from the eyes to the pituitary cause the production of hormone to cease, and *vice versa*. The hormone is carried round in the blood and wherever blood containing a supply of the hormone reaches a pigment cell, the pigment spot expands and helps to darken the skin.

Hormones are of supreme importance in controlling growth and development (in fact, some biologists prefer to speak of many of them as *growth-controlling substances* or as *organisers*). Thus, among the many hormones made by the pituitary gland are some which control the growth in size, particularly of the bones. In human children, *thyroxin*, the hormone made by the thyroid gland at the front of the neck, plays a large part in controlling not merely physical but mental development: if it fails to function properly the child becomes stunted in stature and mentally deficient.

Development changes as varied and complicated as those involved in the metamorphosis of the tadpole to frog quite obviously need to be co-ordinated with one another and we find that they are all controlled by this same thyroid gland. If we take tadpoles in early summer before they are large enough for normal metamorphosis and feed them on thyroxin, they begin their metamorphosis with astonishing rapidity and in a few days become very tiny frogs—if they manage to survive such violent changes. On the other hand, a tadpole whose thyroid gland has been removed by an operation continues to grow and grow, but fails to change into a frog at all.

It has been known for some years that certain hormones control growth and development in plants, too, and that these hormones (now usually called *auxins*) are produced by the apex of the growing shoot. The diagrams on the next page give you some idea of the way in which the effect of one of these hormones can be demonstrated.

Another example is furnished by the opening of buds on twigs. Usually the bud at the top of a twig opens in the spring, and those lower on the twig remain dormant. If the top buds are cut off in spring, the lower buds then open. It

appears that a hormone is made by the buds which *are* opening and that this hormone prevents the opening of buds lower on the twigs. This has been proved by placing the buds cut off on small blocks of gelatine (exactly as in the experiments discussed in the previous paragraph). Here again, a hormone oozes out of the bud and is soaked up by the gelatine. If the

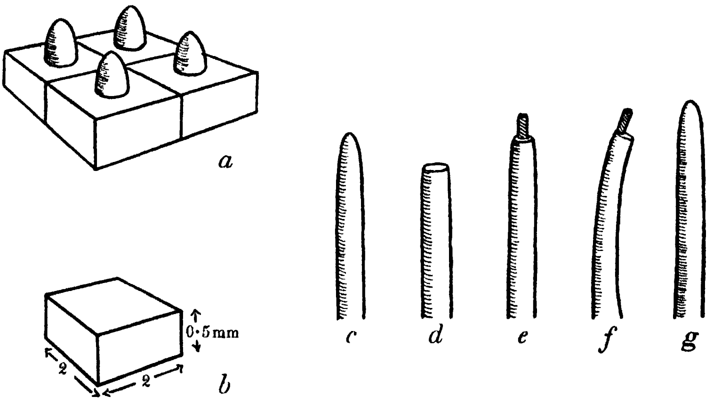


Fig. 123. Experiments demonstrating the action of auxin. *a*, Blocks of agar jelly, each with a tip of an oat seedling: the auxin soaks from them into the agar. *b*, A single block, ready for experiments. *c*, Shoot of an oat-seedling, uncut. *d*, A similar shoot with the tip removed: it does not grow (at least, not for some time). *e*, A shoot, such as *d*, to which a block containing auxin has been fixed: the auxin diffuses into the shoot and growth is promoted. *f*, In this case the block is fixed near one edge of the cut surface: growth on this side is greater than on the opposite side and curvature results. *g*, Normal growth of a shoot such as *c*.

gelatine is then placed on the cut end of the twig this hormone passes down to the other buds and prevents them from opening.

A number of the animal hormones and at least one of these plant hormones have been obtained as pure chemicals and their composition accurately determined. Consequently we have been able to find out what amounts of hormone are necessary to produce the results we observe. As in the case of vitamins, the quantities appear to be almost unbelievably small: it has

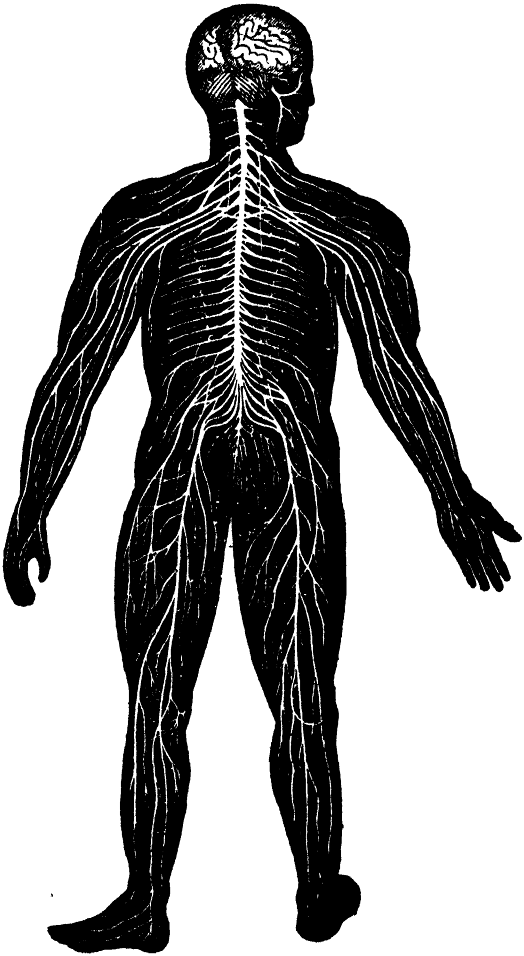


Fig. 124. The nerves serve every part of the body. This diagram shows the general arrangement of the nervous system—brain, spinal cord and some of the main nerves. [From A. V. Hill.]

been shown, for example, that one thirty-millionth part of a milligram of the appropriate hormone is sufficient to cause a curvature of ten degrees in the growing stem of an oat seedling.

THE NERVOUS SYSTEM

Nerves

In a dissection of any large animal it is easy to see some of the nerves. Each such nerve is really composed of an enormous number of nerve fibres, in the same way as a telephone cable is composed of a large number of separate telephone wires insulated from one another. A nerve fibre is a long and extremely thin thread of protoplasm, surrounded by a layer of fat for insulation and a protective coat. Each fibre is part of a nerve cell, the "body" of the cell containing the nucleus being at or near one end of the fibre—usually at the beginning. Around the whole bundle of fibres is a protective sheath of connective tissue.

The nerve fibres can carry messages up *or* down but not both ways. Hence there must be at least two sets of nerves in any part of the body—the *sense nerves* which carry messages concerning stimuli received from without (or within, e.g. messages of pain from the teeth or stomach) and *motor nerves* carrying messages to the muscles and glands which have to perform the appropriate responses.

Nerve Centres

There must, therefore, be connections between the sense nerves and the motor nerves and these are known as *synapses*. At a synapse the incoming nerve terminates in a whole set of fine branches which make contact with similar branches belonging to a number of outgoing nerve fibres. We usually find the synapses grouped together in large numbers to form *nerve centres*. In mammals, these are found mainly in the brain and spinal cord, which together form the *central nervous system*.

In nerve centres in the spinal cord the incoming sense nerves make connections mainly with *association nerve fibres* which carry the message straight up to the brain, from which similar association nerves bring back the reply messages

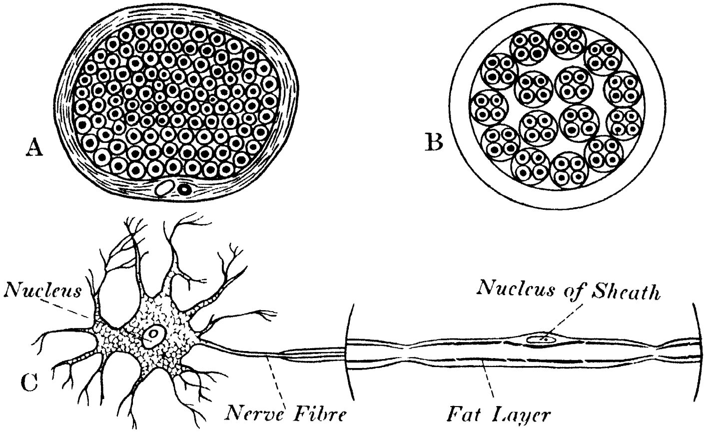


Fig. 125. Nerves. A, A transverse section across a small nerve, showing the various nerve-fibres insulated from one another. In the sheath of connective tissue, are a small artery and a small vein. B, A transverse section of a small telephone cable, showing the wires insulated from one another and enclosed in a lead sheath. C, A single nerve cell, with part of the nerve fibre enlarged even more than the remainder.

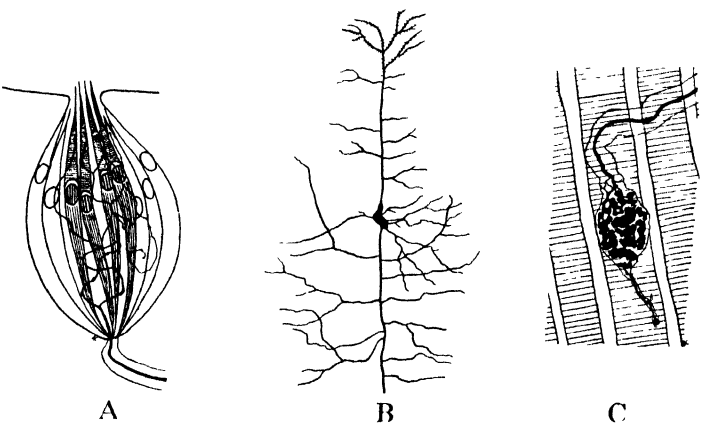


Fig. 126. Nerves. A, A taste-bud in the tongue, with its taste-cells (centre), supporting cells and sense nerve. B, An "association" nerve, from the brain, showing the many fine branches by which it makes connections with other nerves. C, The ending of a motor-nerve in muscle fibres.

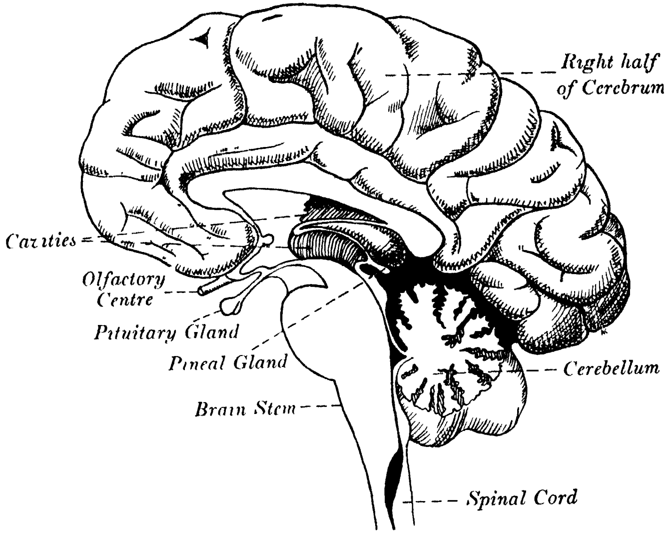


Fig 127. Diagram of brain (cut in halves).
[Redrawn from *The Science of Life.*]

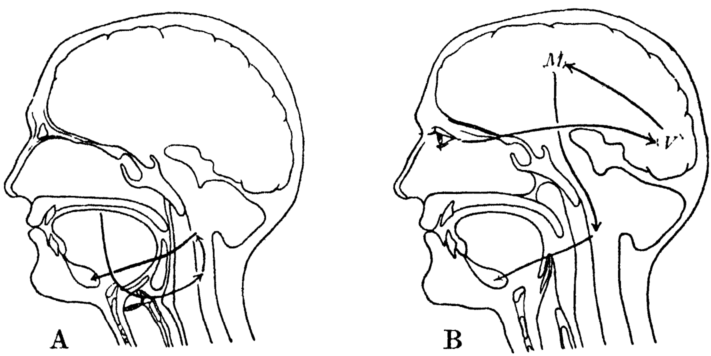


Fig. 128. Inborn and conditioned reflexes. A, The nerve messages involved in an inborn reflex (mouth watering when food is tasted). B, The corresponding nerve messages involved in the conditioned reflex (mouth watering when food is seen). V and M, visual and motor centres, respectively, in the cerebrum. [Redrawn from *The Science of Life.*]

and pass them on to the motor nerves which carry them from the spinal cord nerve centres to the muscles and glands.

The nerve connections at the synapses may be permanent or temporary. In the case of a reflex action the nerve connections are made permanently during the early development of the animal and so normally the nerve messages follow the same path every time and the same response always follows a given stimulus.

Such connections for the simpler reflex actions are found within the spinal cord or in the *stem* of the brain—the stem being the lower part which connects the cerebral hemispheres, cerebellum, etc., to the spinal cord. Connections for complicated reflex actions such as those of balancing are found mainly in the *cerebellum*. The *cerebral hemispheres* contain the connections concerned in reasoning, such connections being merely temporary—though any connection made frequently is more and more likely to become permanent and so give rise to a habit. The cerebral hemispheres are also the seat of consciousness, which is not by any means the same as the power of reasoning: an animal which cannot reason at all may be perfectly conscious of the actions it performs.

THE SENSES

In the previous chapter we stressed the fact that the behaviour of a living organism has to be regulated in relation to what is going on in the world around it, and that changes in the environment, which affect the organism, act as "stimuli" to action. It is obvious, therefore, that all living organisms must be capable of "sensing" at least some of the changes going on around them—that is, in popular parlance, they must have certain *senses*.

Even plants have senses. For most of them, it is sufficient to sense the direction of gravity, the intensity of light and the direction from which it is falling on them, and the direction in which there is a good supply of water. In addition, insectivorous plants and the tendrils of climbing plants are sensitive to touch.

These senses are often confined to certain definite parts of the plant. In the case of the bean root there are special

regions—the tips of the roots—which are sensitive to gravity: it is this part which "senses" the pull of gravity. Similarly, it is not difficult to prove (p. 217, § 3) that in a young oat seedling, the tip of the sheath which covers the young leaves is the part which is sensitive to the direction of light.

Higher animals have a much wider range of senses and possess elaborate *sense organs*. The number of senses is popularly supposed to be five, but is really more than that. Knowledge of the outside world is gained by the senses of sight, hearing, smell and taste and by the sense of "touch". The latter is really a fourfold sense, for in the skin there are four quite separate sets of nerves which give rise to the senses of touch, pain, heat and cold. We can feel the heat of a fire or the cold of a block of ice without touching either the fire or the ice: similarly, a cut or burn on the skin can arouse the sense of pain after the object which caused the injury has ceased to touch the skin.

There are also sense nerves which give us knowledge of what is happening within us. We are normally unconscious of most of these but anyone who has had toothache or stomach-ache will realise that there are pain nerves within the body. Again, when you try to judge the weight of an object by holding it, you are relying on sense nerves which start from the muscles of the arm and let the brain know how strongly those muscles are contracting. This *muscle sense* is very important in balancing, walking and similar activities. A movement such as a high jump or a stroke at cricket involves the carefully co-ordinated movement of a large number of muscles and would be spoilt if even one muscle were to pull too early or too late, too hard or too little.

Sense Organs

Except in the case of the ear and eye, the "sense organs" consist merely of nerve endings which are specially sensitive to certain stimuli. Thus, scattered throughout the skin, just under the living root of the epidermis, are nerve endings of the four skin senses. Some of these nerve endings are sensitive only to touch; i.e., only when the skin covering them is touched do they transmit nerve messages. The nerve endings

of the sense of heat transmit messages only when the skin covering them is heated and do not do so when the skin is touched or cooled. The nerve endings of the sense of cold are stimulated only when the skin covering them is cooled and *in the same way the nerve endings of the other sense nerves are stimulated only by their own particular stimuli.*

The nerve endings of *taste* are found in taste-buds in the mouth mainly on the back of the tongue—and those of *smell* in the top of the nasal passage. These two senses are closely related to one another, for the sense of taste is actually limited to the four tastes of sweet, sour (acid), bitter and salt. All other differences of "taste" are distinguished by the sense of smell: for example, we tell the difference between tea and coffee by means of their different odours and not by any different effect on the taste-buds of the mouth. This explains why we lose practically the whole of our sense of "taste" when our noses are blocked by a severe cold. The "tastes" we lose are those which we distinguish by means of the nose and we are left only with those which are really and truly tastes.

The *eyes* are the sense organs of sight and closely resemble a pair of cameras, except that the sensitive sheet of nerve endings never needs changing but is always ready to receive impressions.

The essential parts of a camera are a sensitive film or plate, a convex lens which forms the image on the plate and a shutter which can open to allow light to enter when we wish to take a photograph. In addition, most good cameras have an iris diaphragm for regulating the depth of focus and the amount of light to be admitted and an arrangement for focusing the lens by moving it backwards and forwards.

In the eye we find a sensitive screen or *retina*, a convex *lens* and a circular sheet of coloured muscles called the *iris*. The whole is enclosed in a tough white outer coat, lined with a black coating which prevents reflection. The front part of the eye is transparent (the *cornea*). The iris muscles open or close the *pupil* (the "black" hole in the iris) according to the amount of light falling on the eye.[1] The *lens* is focused by a set of very

[1] These and the other muscle movements connected with the eye are further very fine examples of co-ordination.

fine muscles which are attached around its edge: when these tighten the curvature of the lens is lessened and consequently the eye is focused or *accommodated* for distant vision; and when the muscles are slackened the curvature of the lens becomes greater and the eye is focused for seeing things close at hand. Normally the curvature of the lens can be increased until it is possible to focus objects only ten inches from the eye. In children, the lens is very elastic and objects *can* be

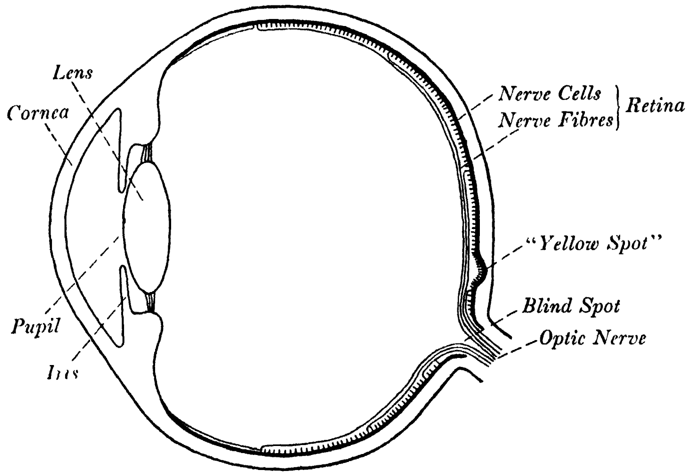


Fig. 129. Diagram of the eye (vertical section).

focused even at a distance of four inches. This, however, strains the eye very considerably and children who make a habit of reading and writing with their books less than ten inches from the eyes are liable to become permanently short-sighted.

The nerve fibres attached to the nerve endings on the retina do not, as we might expect, pass out through the back of the eye, but actually come into the eye and pass over the other nerve cells of the retina before they all leave the eye as one large *optic nerve*. Fortunately the layer of nerve fibres lying on top of the sensitive nerve endings is transparent or such an

arrangement would not work: but where all the nerve fibres leave the eye there is no room for nerve endings and that place is rightly called the *blind spot*. On that part of the retina immediately opposite the pupil, the *yellow spot*, the nerve endings are much more concentrated than elsewhere and so vision there is more precise.

Muscles at the back of the eye are responsible for turning the two eyes so that both look at the same thing: you can easily see this if you watch a friend reading. Since the two eyes are a few inches apart, they do not see quite the same "picture". The two pictures are "flat" like a photograph but the brain combines them in such a way that one "solid" picture is obtained.[1] This is what is meant by *stereoscopic vision*.

The *ear* serves as the sense organ for the senses of both hearing and balance: its structure is illustrated in Fig. 130. If you see a tuning fork or violin string causing a sound, you will notice that it is vibrating. All sounds consist of vibrations or waves of frequencies ranging from about 20 to 25,000 waves per second. These vibrations usually travel in air; but they can travel equally well, or even better, in liquids or in solids, as you will know if you have ever heard sounds when swimming with your head under water or have ever listened, with your ear to the ground, to footsteps some distance away.

In the ear, the outer ear flap (1) concentrates the sound vibrations to some extent, though it is far less efficient in man than it is in many of the other mammals (e.g. horse, dog, elephant). The vibrations then travel down the air of the *outer ear passage* (2) to the *ear drum* (3) which is made to vibrate and in turn passes the vibrations on, *via* the bones of the middle ear—*hammer* (4), *anvil* (5), and *stirrup* (6)—to the *perilymph* liquid which surrounds the *cochlea* and which is shown black in our diagram. Finally the vibrations are passed to the endolymph within the cochlea (10). Here there is a whole series of nerve endings, each of which is stimulated only when its own particular note is "heard": the nerve endings at the larger end of the cochlea are stimulated by the lower notes

[1] When a person is drunk, the brain fails to do this and he "sees double".

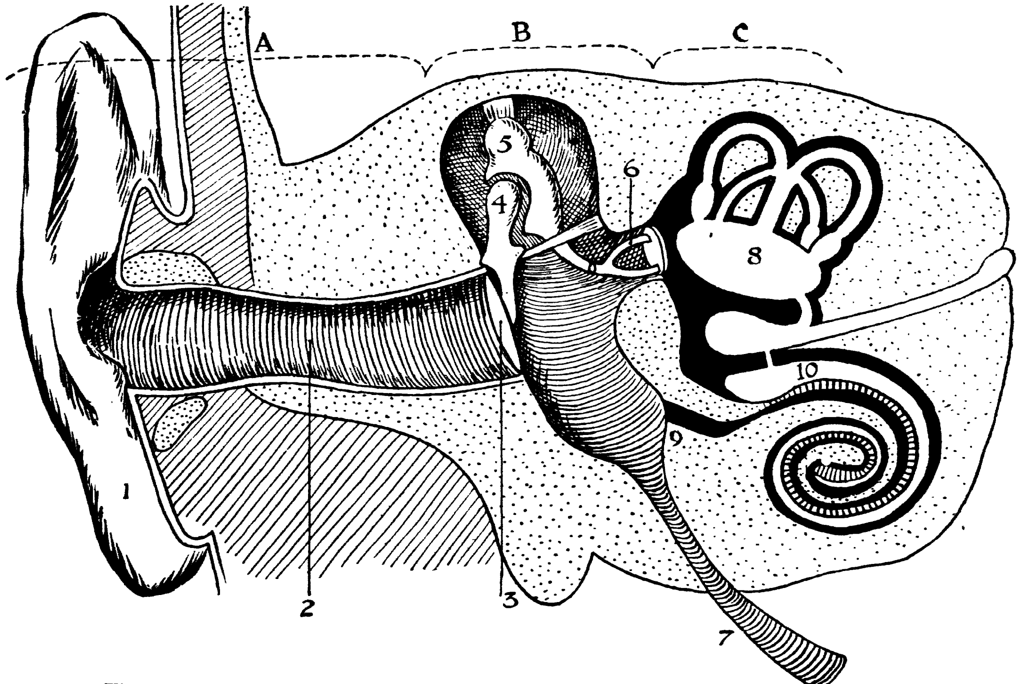


Fig. 130. Diagram of the human ear. A, outer ear; B, middle ear; C, inner ear. See description in text. [After J. A. Thomson.]

and those at the smaller, inner end are stimulated by the higher notes.

The middle ear is filled with air and by means of the *Eustachian tube* (7) which communicates with the back of the nose, the air pressure is always kept the same on the two sides of the ear drum. This is important since any excess of pressure on one side or the other would hold the drum rigid and prevent it from vibrating freely. The *membranous window* (9) is pushed outwards when the stirrup bone (6) is pushed inwards, and so renders it easier for sound waves to travel in the perilymph.

The three *canals* shown (8) are the part concerned with the sense of balance. They are approximately circular, are arranged at right angles to one another, and they are filled with a liquid, *endolymph.* It is the varying pressures and the movements of this liquid which stimulate the nerve endings in the walls of the canals and enable the brain to judge the position and movements of the head. With this and other information gleaned from the eyes and the sense nerves of muscles, the cerebellum is able to control the balancing of the body.

PRACTICAL WORK

1. The part played by the hormone, thyroxin, in the metamorphosis of tadpoles can be demonstrated. Place half a dozen tadpoles, whose back legs are just appearing, in an aquarium jar with water weeds and add one or two powdered 1 gr. tablets of thyroid extract. Set up a control experiment by placing six other similar tadpoles under conditions identical except for the addition of thyroid tablets, and compare results.

2. Examine the "cranial nerves" (i.e. the nerves connected direct to the brain) as seen in the dissection of a dogfish and the "spinal nerves" (i.e. those connected to the spinal cord) as seen in the dissection of a frog With care, the brain may be removed from the skull of a rabbit and cerebrum, cerebellum, etc., identified.

3. To find out which part of the stem of an oat seedling is the "sense organ" for light, germinate some oats in the dark until the shoots are about ½ inch long. Divide them into four lots and treat them as follows:

First lot: cover their tips with tiny caps of tinfoil, made by wrapping the foil round a pencil tip.

Second lot: fit them with collars of tinfoil, leaving the tips exposed.

Third lot: cut about 2 mm. off the tips.

Fourth lot: untouched.

Enclose the seedlings in a box with a small hole at one side, so that light falls on them from that side only, and leave them for a day or two. What are the reactions of the seedlings, and what conclusions can you draw?

4. A similar experiment may be performed to find out which part of the root is sensitive to gravity. Take some broad bean seedlings with straight roots about an inch long and cut about 2 mm. off the root tips of some of them. Fix the beans, with the roots horizontal, in a wide bottle lined with damp blotting paper which dips into water at the bottom. Compare the results after a day or so. To find out which part of the root is responsible for the *response* to the stimulus, mark the roots as in Fig. 157.

5. The sense organs of the skin can be explored as follows. Put a knitting needle (or the point of a pencil) very lightly on the upper side of the wrist or on the cheek below the eye: at certain spots an intense feeling of cold will be noticed. In the same way, test for *heat-spots* (especially at the elbow) with a warm knitting needle, *pain-spots* by pressing with the point of a pin or needle, and *touch-spots* by pressing with the point of a fairly stiff bristle mounted on a holder.

6. Test your muscle sense by closing your eyes and letting someone else move your left arm into a new position: can you then touch the forefinger of the left hand with the forefinger of the right hand at the first attempt? Again, compare the apparent weights of an object held first in the outstretched hand and then with the hand resting on a table (note that the muscles are used only in the first case).

7. The eye of an ox can be dissected quite easily, even with a safety-razor blade, by removing any fat from the outside (notice the stumps of the external muscles and of the optic nerve) and then cutting the front half away from the back half. Identify the various parts and make a plasticine model.

8. With the aid of a mirror, investigate the way in which the pupils of your eyes open and close in different intensities of light.

9. Watch the movements of a friend's eyes as he looks at objects near and distant, and when he is reading.

10. Try to touch a small object at arm's length with the forefinger, bringing the arm in from the side (*a*) with one eye shut and (*b*) with both eyes open. Do you find any difference in the ease with which you judge the distance and position of the object in the two cases?

11. Take a piece of paper and on the left of it mark a cross about $\frac{1}{4}$ in. across. About 3 in. to the right make a spot about $\frac{1}{4}$ in. across. Close the left eye and look fixedly at the cross with the paper about 15 in. away. Slowly bring the paper nearer, looking hard at the cross all the time, and when the paper is about a foot away the spot disappears: its image has fallen on the blind spot.

12. Examine a model of the ear. Semicircular canals are seen in a dissection of the head of a dogfish (as are the olfactory organs of the nose).

(For other practical work on the sense organs of the human body, see J. A. Dell's *Gateways of Knowledge*.)

CHAPTER XIV

REPRODUCTION

Kipling has quoted the "Law of the Jungle" as "Eat and be eaten" and what we have noted in the chapters on food cannot but have impressed us with the enormous numbers of living things that die by being eaten. Even those which are too large to be eaten by things larger than themselves (and this is true also of man) are attacked by enemies within- by parasitic microbes, fungi, etc.—which may eventually cause the death of their unwilling "hosts".

It might, perhaps, be said that "natural death" is rare among animals, but the possible life-span of all but the simplest of living things appears to be limited[1] and death must come soon or late. Among human beings (and in some of the other large animals) cases *do* occur in which the tissues seem simply to "wear out" and, when some essential organ fails to do its job, the organism as a whole dies.

Among plants the facts are essentially the same but "natural death" would seem to be the general rule, for there are thousands of annual plants that complete their life-span in the autumn and die as winter sets in. In these cases life may sometimes be prolonged under artificial (e.g. greenhouse) conditions but death occurs even then after a short interval. The *ephemerals* of deserts behave similarly. They grow from seed when rain falls, flower and seed with great rapidity and die off again as the desert dries. The name "ephemeral" really means "lasting for a day" and emphasises the short life—usually several weeks, however —of these plants. On the other hand, some trees appear to be potentially immortal. There is a mechanical limit to the height to which water can be drawn but they can continue to grow *outward* indefinitely (see frontispiece). Few trees, however, live to be more than a thousand

[1] There appears to be no such thing as "natural death" for such simple organisms as Amoeba Spirogyra and bacteria.

years old because, even if they are not attacked and killed by fungi, lightning, fire or high wind cut short their span.

It is obvious, then, that each kind of living thing must be capable of replacing its dead—i.e. must *reproduce*—if it is not to become extinct. Since death will often overtake an individual before it has reproduced, those individuals which do reach maturity must produce several offspring if numbers are to remain constant. The necessary number of offspring will vary enormously from species to species. Under natural conditions the elephant has a long life-span and few enemies. It reproduces only after many years and the number of young is small, but sufficient. Many fish, on the other hand, lay millions of eggs and though many of these are eaten enormous numbers hatch into small fish. These have so many enemies and so few survive that, despite the abundance of eggs, the number of adults remains fairly constant from year to year.

VEGETATIVE AND ASEXUAL REPRODUCTION

In dealing with Amoeba we have seen the simplest type of reproduction—a splitting, or *fission*, of the organism into two as its protoplasm increases in bulk. The same method is used by bacteria (p. 259) and other small organisms. Very similar is the reproduction of yeast. When it is well fed each cell simply buds off new cells and these break away, grow up and become new yeast cells (Fig. 96). The same sort of budding is found in simple animals of which *Hydra* is an example. This is a small animal, like a tiny green sea-anemone, which lives among the weeds of fresh-water ponds.

We cannot expect more complicated animals and plants suddenly to split into two but, in plants with underground stems or *rhizomes*, we find something very similar. In plants such as the iris, couch grass and bracken, the underground stems grow forward each year and branch not infrequently. The oldest part of the stem dies off and so the new branches become separate plants. The strawberry plant, near the end of each season, forms *runners*—thin red stems which form new plants at some distance from the parent. By pegging down

these runners, strawberry growers can thus obtain new plants just where they want them! The potato plant grows its *tubers* as swellings on the end of thin, white, underground stems and these tubers, whether left where they are formed or dug up and planted elsewhere, grow into new plants in the following spring. Similarly the crocus forms new *corms*[1] while plants with *bulbs* reproduce by making new bulbs within or at the side of the parent.

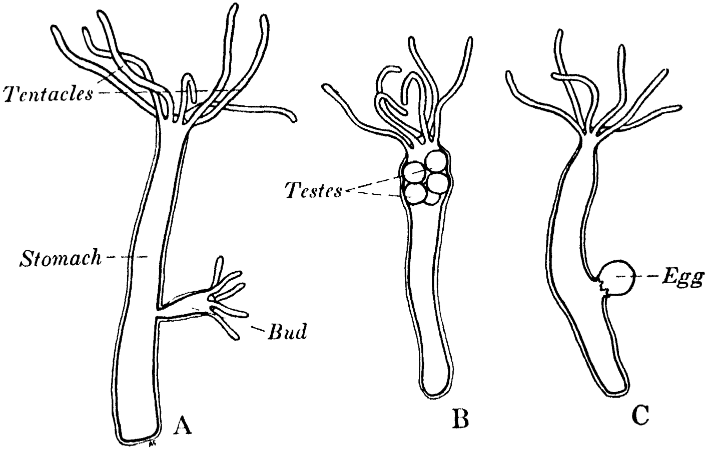


Fig. 131. Reproduction in *Hydra*. A, Budding. B, Hydra with testes. C, Hydra with an ovary, from which an egg is escaping.

Methods of reproduction such as these, which do not involve any "fertilisation" (p. 225), are spoken of as methods of *asexual* or *vegetative reproduction*.

Cuttings, of course, are an artificial method of vegetative reproduction and *propagation* by this means is an important feature of gardening. A twig (sometimes, as in begonia, a leaf may be used) is taken from the parent plant, stuck in the

[1] You would suppose that since the new corm is formed *on top* of the old one, it would be a little nearer the surface of the soil. This, however, is prevented by curious *contractile roots* which drag the corm more deeply into the earth.

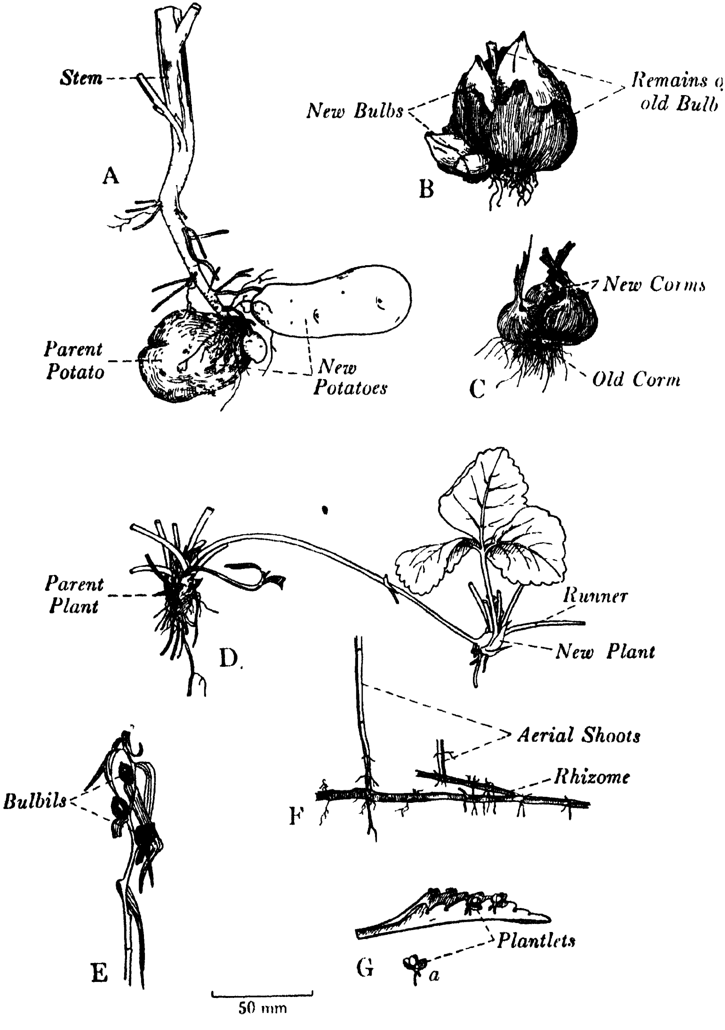


Fig. 182. Vegetative reproduction in flowering plants: natural methods. A, Potato. B, Tulip. C, Crocus. D, Strawberry. E, Lily. F, Mint. G, Kalanchoe (a South African plant). [Bulbils are small bulbs which grow on the stem and not underground.]

ground and left to grow new roots. In some species, this happens quite rapidly, provided that the cutting contains sufficient food and water. In other species, root formation is slow and water loss from the cutting may cause death. This may be avoided by keeping the cutting in a more or less water-saturated atmosphere and to provide this gardeners use closed "propagating frames".

Sometimes the cutting (or *scion*) is *grafted* on to the stem of another growing plant (or *stock*) so that the two grow together and form a new plant. The stock is often a wild plant—thus

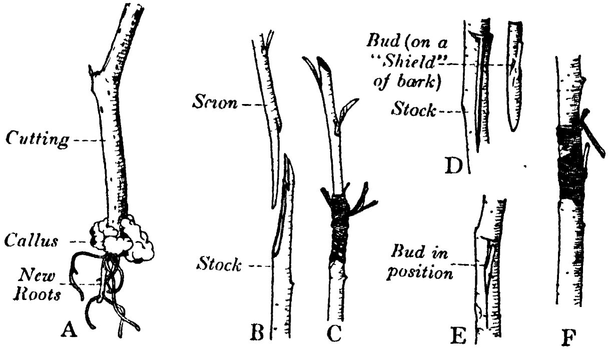


Fig. 133. Vegetative reproduction in flowering plants: artificial methods. A, The growth of new roots on a cutting. The cut end has been healed by a growth of "callus"—an unusually vigorous growth in this case. B and C, The process of grafting (the join is covered with wax to prevent loss of water by evaporation). D–F, The process of budding.

wild (briar) roses are used for grafts of the various garden roses. In these and other cases the scion takes water and salts from the stock and is not greatly affected by the fact that it is not using its own roots. The fact that stock and scion retain their own characters is really very surprising, especially when scion and stock are taken from rather distantly related and very different plants.

Since the scion does not need a large food store of its own it is often sufficient to take just a *bud* of the variety which it is desired to propagate and to graft that on to a stock stem—such a procedure is called *budding*.

The following brief list will give you some examples of plants in which these methods are used:

NATURAL VEGETATIVE PROPAGATION

Rhizomes: mint, couch grass, iris, bracken.
Suckers (short rhizomes): banana, raspberry.
Runners: strawberry.
Tubers: potato, dahlia, Jerusalem artichoke.
Corms: crocus.
Bulbs: onion, lily, daffodil.

ARTIFICIAL VEGETATIVE PROPAGATION

Cuttings: Leaf: begonia.
Stem: geranium, dahlia, fuchsia, carnation, currant, gooseberry.
Root: horse-radish.
Grafting: apple, plum, pear, seedless orange, grape.
Budding: rose, apple, plum, pear, cherry, peach.

Except for bracken, all these are *flowering* plants. Most *non-flowering* plants (e.g. fungi) reproduce asexually by forming *spores* -tiny bodies as fine as dust—which may be carried for long distances before growing into new plants. Even here, however, the process is frequently linked up with sexual reproduction and may alternate regularly with it —giving rise to the complicated but interesting *alternation of generations* which is shown so well by the common ferns (p. 230).

The great characteristic of asexual reproduction is that the offspring are exactly like the parent. When the gardener wishes to propagate a useful or attractive variety of plant he usually resorts to vegetative propagation, knowing that in this way he will preserve his variety unchanged. Thus he reproduces good varieties of potato by means of tubers, of roses by budding and of fruit trees by grafting. If he collects and sows seed, on the other hand, the results are nearly always disappointing to him, few of the seedlings being just like the desired plant. We say that the variety does not "breed true". In some cases, and particularly when two varieties are "crossed", a proportion of the seedlings may be *better* than either of the

parents and these are selected and used as new material for vegetative propagation or for "crossing" again in an effort to get even better plants. It is usually by such methods that new varieties are obtained.

SEXUAL REPRODUCTION

This is the usual method of reproduction for practically all animals and is also found in the life history of most plants.

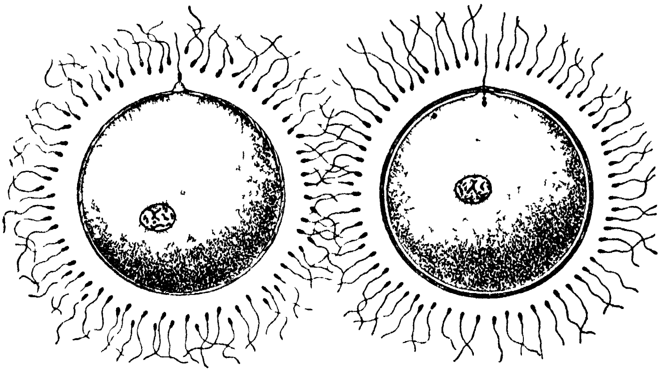


Fig. 134. Fertilisation in a sea-urchin's egg: the entry of the sperm. A cloud of sperms gathers around each egg, but only one enters. Note the female nucleus within the egg, the male nucleus forming the head of the sperm and, in the second drawing, the fertilisation membrane which forms around the egg immediately the sperm enters. [From Fox.]

There are normally two types of reproductive bodies or *gametes* formed. In most cases, the female gamete is an *egg* and the male gamete a *sperm*, though in flowering plants we find a special type of egg cell contained in an *ovule* and the male gamete carried in the *pollen grain*. Before a female gamete can begin to develop into a new individual, it must be *fertilised* by the joining on, or *fusion*, of a male gamete. The cell resulting from the fusion is called a *zygote*. Each gamete carries a single nucleus and *it is the fusion of a male and a female nucleus to form the first nucleus of the new individual that really constitutes fertilisation and is the essential element in sexual reproduction.*

In a few simple organisms—e.g. *Spirogyra* (p. 27) and *Mucor* (p. 118)—the gametes are all the same: the joining of the gametes is then spoken of as *conjugation* and not as fertilisation. The whole process, however, is still called sexual reproduction since it involves a joining of nuclei.

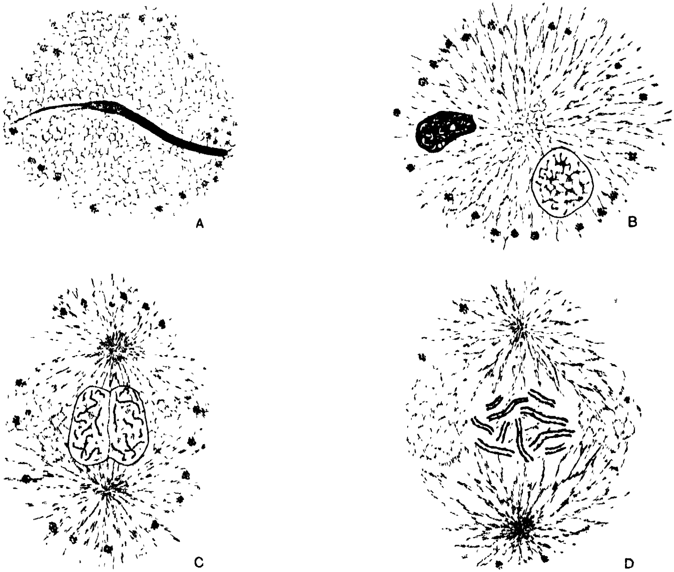


Fig. 135. The joining of the nuclei in fertilisation. A. The head and a small part of the tail of a sperm in the protoplasm of the egg. *Only a small portion of the latter is shown.* B. Sperm-head swelling up and so gaining the appearance of an ordinary nucleus: female nucleus has entered the same portion of the egg. C. Male and female nuclei ready to join: the rods which have appeared are the "chromosomes", carriers of inheritance. D. Nuclei joined: note the way in which the chromosomes have paired. (Modified from Jenkinson's drawings of Axolotl fertilisation.)

Fish may be taken as a first example. In many species the fish collect together in enormous numbers on the breeding grounds (that of the plaice is about half-way between London and the Dutch coast). Thousands of eggs are formed in the *ovaries*—the "hard roes"—of each female fish and pass through

the *oviduct* into the sea. The sperms form in the *testes*—the "soft roes"—of the male and are also passed out into the water.

The egg is quite small and contains a single female nucleus, a small amount of protoplasm and a store of food or *yolk* from which more protoplasm can be built up as the embryo fish

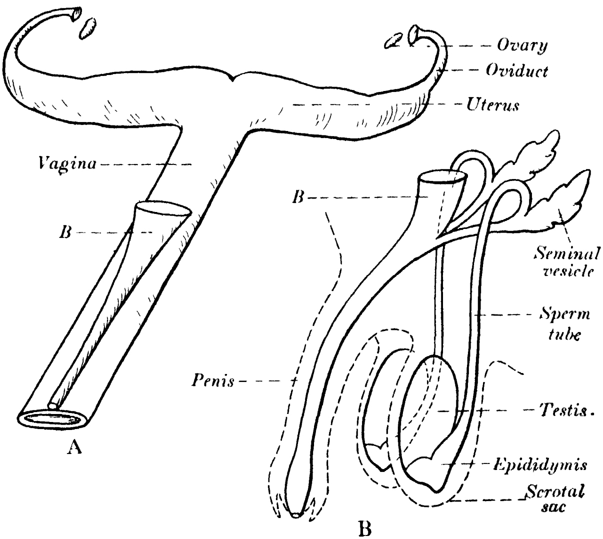


Fig. 136. The reproductive organs of a typical mammal. A, Female in an early stage of pregnancy. B, Male. (The base of the bladder (*B*) is also shown in each case, since the urinary system is closely associated with the reproductive organs.)

develops. The sperm is even smaller, containing only a male nucleus and a tail of protoplasm by means of which it swims. Normally the number of sperms formed is thousands of times greater than the number of eggs and they swim about until, attracted probably by some chemical substance which escapes from the egg, they gather in large numbers around the latter. One sperm (and usually one only of all the thousands) enters each egg, the surface of which is immediately changed so that no more sperms can enter. The two nuclei then join to form one

nucleus. The spare sperms and any unfertilised eggs are simply wasted as far as reproduction is concerned, though they will certainly form food for other living organisms.

The same story is true, though we do not speak of "ovaries" and "testes", of many seaweeds (p. 237, § 11), but this rather haphazard way in which eggs and sperms are left to meet is very wasteful, though its risks are minimised to some extent by chemical attraction (see p. 237, § 13). In some fish (e.g. salmon and goldfish) we find that the male attends each female and releases its sperms as the eggs are discharged into the water, while in frogs the male sits on the female's back and pours the sperms over the eggs as they are laid. Such arrangements for *pairing* cut down the wastage of sperms and ensure that practically all the eggs are fertilised.

Where eggs are laid on land (e.g. most insects, reptiles and birds) there must be a shell to prevent the egg from drying up. This shell is formed around the yolk in the lower part of the oviduct and fertilisation, of course, must take place before this happens. Here pairing is a necessary part of the reproductive processes: the male passes the sperms, mixed with a liquid, into the body of the female where they swim up the oviduct and fertilise the eggs.

The same thing happens in mammals. In these animals the egg is not "laid" at all, but is retained in a part of the oviduct, called the *uterus*, and develops there (p. 250).[1] Hence fertilisation must take place in the uterus and again the sperms and sperm liquid are transferred from the body of the male to that of the female and the sperms swim up into the uterus and fertilise the eggs there. The reproductive organs of typical male and female mammals are shown in Fig. 136. In the male, the sperms formed in the testes are stored temporarily in the epididymes and later passed up the sperm tubes and out of the body through the penis. The seminal vesicles and certain other glands produce a liquid which mixes with the sperms on their discharge and which appears both to nourish and to activate the sperms. The sperms and the liquid together are known as *semen*.

[1] A female mammal is said to be *pregnant* during the period when young are developing within her.

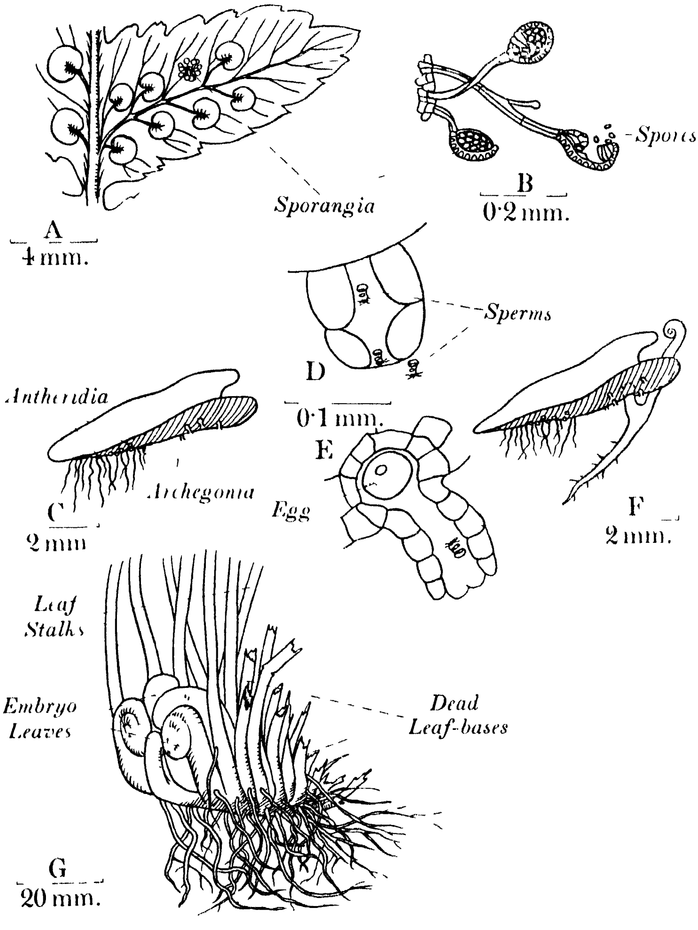


Fig. 137. The life history of a fern. A, A small part of a fern leaf, showing groups of sporangia (one without the usual cover). B, Three sporangia, one opened and releasing its spores. C, A prothallus. D, An *antheridium* (the organ in which sperms are formed), with sperms escaping. E, An *archegonium* (the organ in which the egg is formed), containing an egg. F, The embryo of a new fern plant, living for its start, as a parasite on the prothallus. G, The underground parts of a mature fern plant.

Sexual reproduction in non-flowering plants is well illustrated in the mosses. Here eggs and sperms are produced at the tops of little upright branches—usually the "male" and "female" occur on different branches. It was once thought that the moss sperms swam from the male to the female branches when the plants were wet with rain or dew—which would be a very long journey for such small things. Recent observation has shown that, in some cases at least, tiny mites visit both types of branches in search for an attractive jelly that is also produced and that in so doing they carry sperms to the egg-bearing stems! From the fertilised egg grows a small, asexual plant, parasitic on the parent plant and consisting of an absorbing foot which gets food from the parent, a stalk and a capsule. This last is a small, brown, stalked structure, which produces spores. These grow into new moss plants.

In ferns, spores are formed in little bags on the backs of the leaves (groups of these bags are visible as small brownish patches). A spore never grows directly into a fern plant but forms something quite different—the *prothallus*—a flat, green plant about a centimetre in diameter. This in turn forms the eggs and the sperms which fertilise them, and the new fern plants grow from the fertilised eggs. We therefore find an alternation of two distinct generations—a fern-plant generation which produces spores, followed by the prothallus generation which bears the gametes, followed by the fern plant again and so on. This is the alternation of generations to which we referred previously.

In the plants with which we are most familiar—the flowering plants—the sperms consist merely of the male nuclei and have no tails. There is no water in which they can swim from one flower to another and we find that they are carried in the pollen grains. The ovary is hollow and contains one or more *ovules*, or embryo seeds, within which are the egg cells each with its female nucleus. The pollen grains are collected by the *stigma* at the tip of the ovary and then each grows a fine *pollen tube* down to an ovule. Through this tube the male nucleus passes to join, and so fertilise, the female nucleus of the egg cell.

Pollen is formed in the stamens of the flower and it is

Fig. 138. Pollen grains of the sweet pea, developing pollen tubes in sugar solution. [Photo: R.D.G.]

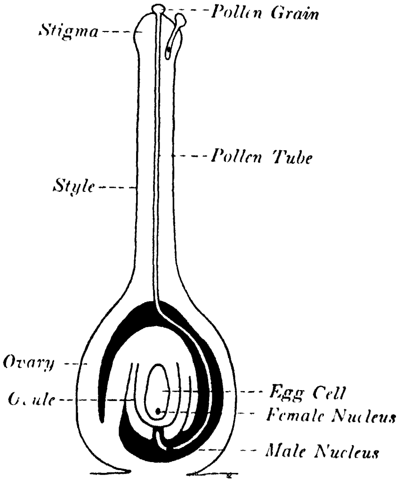


Fig. 139. Fertilisation in the flowering plant (simplified).

usually carried from one flower to another by such insects as bees, moths and butterflies: in this way *cross-pollination* is ensured. The insects visit the flowers to gather nectar[1]—the brightly coloured petals and the scent, if any, acting as advertisements to them—but they find the nectar so hidden that they cannot take it without getting pollen deposited on them. When the insect visits the next flower of the same species the stigma is in such a position that it takes off some of the pollen the insect is carrying and so fertilisation is ensured. In a greenhouse where insects do not normally enter, it may be necessary for the gardener to carry the pollen from flower to flower on a camel's-hair brush. Even with plants in the open (e.g. fruit bushes) this *artificial pollination* may help to increase the yield: in a recent experiment the yield of many varieties of black currants was doubled by this means.

Some flowers have their pollen carried by the wind. These usually have neither petals nor sepals and so are very inconspicuous: frequently they are green and bunched together in long hanging *catkins*, e.g. hazel, oak. Grasses and cereals are also wind pollinated (often, very early in the morning). Their flowers are characterised by stamens with long, thin filaments and prominent, feathery stigmas. The process is apt to be very wasteful since so little of the pollen arrives on the stigmas, and we find that plants in which it occurs make very large quantities of pollen.

Other flowers are *self-pollinated*, i.e. they have some arrangement by means of which their own pollen is used instead of that of another flower. The bee-orchid is an example of this: the pollen is formed in two club-shaped masses which bend over when mature and come into contact with the stigmas of the same flower. Our photograph shows two flowers "caught in the act".

DISPERSAL

One problem which arises in connection with reproduction is that of dispersal. If all the offspring of a living thing stayed where they originated, a hopeless state of overcrowding would

[1] In some cases (e.g. poppy) there is no nectar but some of the pollen itself is taken away and eaten.

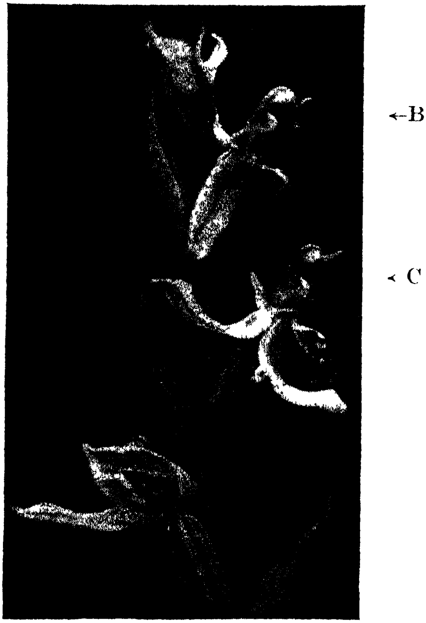


Fig. 140. Self-pollination in the bee orchid. For explanation see below. [Photo: R.D.G.]

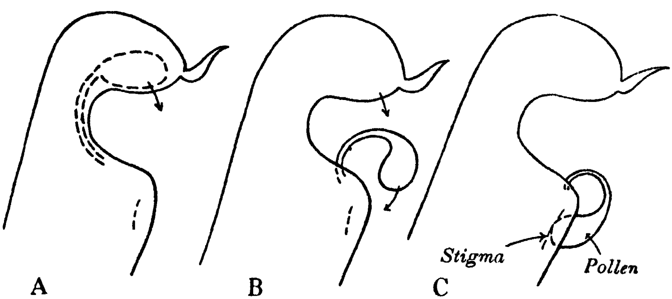


Fig. 141. Self-pollination in the bee orchid. The pollen develops in two masses in the position shown in A and, when ripe, bends over until it touches the stigma below, B and C (see above).

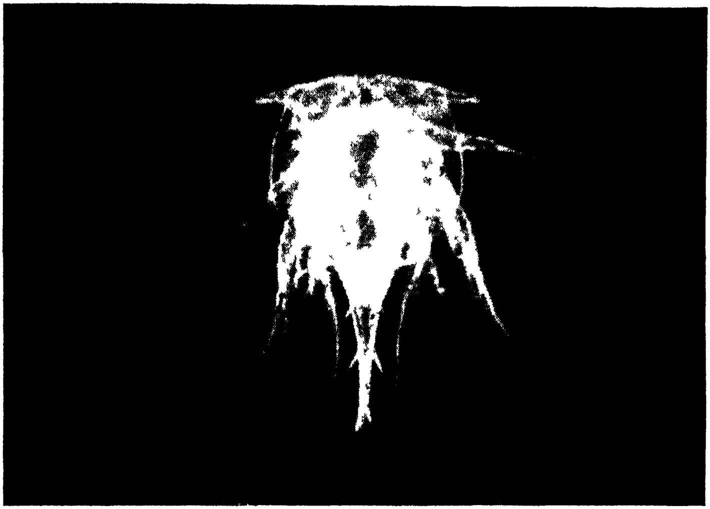
result and life for both parents and offspring would become impossible. If, on the other hand, there are methods by which the offspring may spread to new places they will at least be fairly evenly spread over the areas available to them.

Most animals are able to move about from place to place and so they need no special methods of dispersal, but it is interesting to find that animals which spend the greater part of their lives fixed to one spot (e.g. barnacles) or can move only to a very limited extent (e.g. starfish and sea-anemones) have larvae which are capable of swimming or drifting about in the surface waters of the sea.

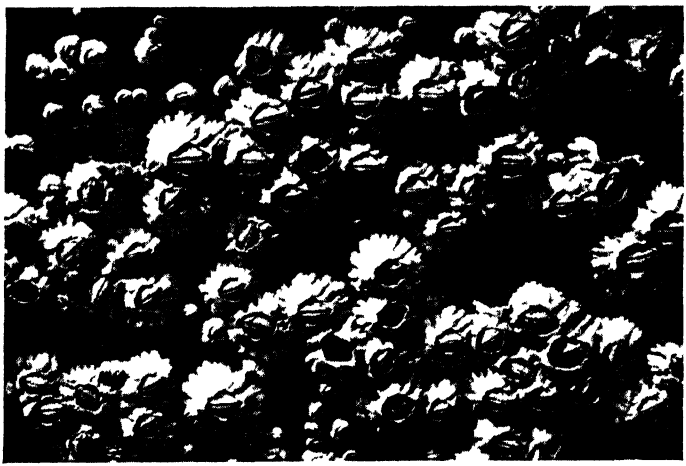
Among plants, almost all non-flowering plants have spores so minute that they are readily blown about in the air and so it is only among flowering plants that there is any necessity for special arrangements which ensure dispersal. The parts of the plants used for dispersal are the seeds (or the fruits which contain them). Each seed contains an embryo plant, a food store and a protective covering (p. 243).

Some seeds are almost as small as spores and so are blown about by the wind: thus many of the orchids make a million or more seeds in a pod an inch long. The fruits of such plants as poppy and campion open only at the top and consequently the seeds do not fall out unless the wind is blowing hard enough to sway the fruit to and fro on its stalk and to carry the seeds away (this arrangement is often spoken of as a *censer mechanism*). Other very light seeds and fruits bear long hairs and so present a greater surface to the wind: willow and willowherb ("fireweed") have hairy seeds while clematis, thistle and dandelion have hairy fruits. Many trees (e.g. sycamore, lime, elm and ash) have winged fruits: the wing makes the fruit spin as it falls so that it takes very much longer to reach the ground and consequently is blown much farther away by the wind than would otherwise be the case.

Nuts such as acorns and beech "mast" are often taken by squirrels and buried some distance from the parent tree and, if they are forgotten, grow where they are left. Other fruits (e.g. agrimony, goosegrass and the various "burrs"—burdock in England and Canada; Bathurst burr and sheep's burr in Australia) are hooked and so catch in the fur of passing animals.



A



B

Fig. 142. The common acorn barnacle. A, The free-swimming larva: × 60 B, Adults, with their shells closed up: × ½. [Photos: D. P. Wilson.]

Birds are responsible for dispersing the seeds of juicy and fleshy fruits, such as hips and haws and all the different types of berries. They eat the soft part and either spit out the seed immediately or swallow it and, since it is indigestible, pass it out later. A third alternative arises when the pulp of the fruit is very sticky, as in mistletoe: the seed usually sticks to the bird's beak and has to be wiped off. This is an obvious advantage to the mistletoe since the bird is quite likely to wipe the seed off on a twig or a crack in the bark of a tree—and it is only in such positions that mistletoe can grow.

Some fruits are "explosive" (e.g. broom, gorse and balsam), bursting open in such a way that the seeds are flung out: others, like coconuts and mangroves in the Pacific Ocean, are carried by ocean currents. The so-called "double coconut," which is the fruit of a palm, was often found floating in the Indian Ocean—long before the tree itself was discovered growing in the Seychelles Islands.

In all the cases we have mentioned so far, the seeds or fruits are specialised, or *adapted*, for their particular mode of dispersal. Finally, we must mention one other way in which fruits and seeds are dispersed—a method which might almost be classed as accidental but which is nevertheless quite as important as any of the others, and is probably the only method by which they are dispersed over long distances. We refer to the fact that birds often carry seeds and fruits in the mud on their feet. The great biologist, Darwin, was once given a duck which had been shot while on migration and he carefully germinated all the seeds which he could wash off the bird's feet—and was surprised to find that he got dozens of different species of plants, many of them foreign. It is suspected that it is in this way, also, that starlings bring the germs of foot-and-mouth disease to England from the Continent; and the increasing volume of aeroplane traffic is providing a dangerously efficient method of transmitting plant and animal diseases and parasites from one country to another.

PRACTICAL WORK

1. Keep *Hydra* in an aquarium tank. Feed well on water-fleas, etc., and watch during the summer for budding.

2. Examine a bed of iris or bracken, excavate some of the rhizomes and notice the method of growth.

3. Examine runners of strawberry in late summer when the new plants are developing.

4. Notice the eyes (buds) on potato tubers. Examine the growth of new shoots in spring and dig up a plant in midsummer to see the formation of tubers. Cut thin slices of the stem running to a tuber and of a young and of an old tuber Test each section for starch (with iodine solution). Is starch present in all three sections?

5. After a crocus has flowered dig up the corm and look for the swellings at the bases of the aerial shoots which are the new corms. Look also for the thick wrinkled "contractile" roots.

6. In the same way open up bulbs some time after flowering and look for the new bulbs within the old ones.

7. Put cuttings of willow, apple, poplar, pine, etc., in moist sand. Which of them root readily? If possible keep similar cuttings in moist sand *under a glass jar*. Will they root? (It is important to allow several months to pass before abandoning this experiment.)

8. Detach the head from a newly expanded mushroom and place it gills down on a sheet of white paper. Cover it with a glass jar and leave it undisturbed overnight. Note the beautiful "spore-print" formed by the thousands of spores that have been discharged.

9. Examine prepared slides of testes to see developing sperms.

10. Open a freshly killed earthworm and place the contents of the seminal vesicles (labelled "reproductive organs" in Fig. 10) in 0·75 per cent. salt solution. Notice the sperms swimming about.

11. Look for the brown "bladderwrack" seaweed (*Fucus*) on the shore between tide levels. Collect some that shows swollen, warty tips. Hang this in the air for a while and note that as it dries out jelly is squeezed from the tips. Notice that some plants give green slime and some orange. The former contains eggs: the latter sperms. Mount in sea-water and examine under the microscope. If you mix the two jellies it is sometimes possible to observe fertilisation. (Note: *Fucus* grows between high and low tide levels so that it is regularly left to dry for a time. The jellies are exuded during this period of drying and are washed off when the tide rises, fertilisation then taking place in the water. After fertilisation the egg sticks to a rock or other submerged object and grows into a new plant. Notice when you visit the seashore that some kinds of seaweeds grow near high-water mark, others a little farther down and still others, especially the red seaweeds, at or below low-tide mark.)

12. Examine dissections to show reproductive organs in fish, frog, rabbit, etc.

13. Mount a mature fern prothallus in water on a microscope slide. Examine it and note the reproductive organs with sperms and eggs. The

latter may often be seen swimming rapidly about in the water. Introduce a very slender capillary tube containing a dilute solution of malic acid (or better a solution of a soluble salt of the acid). Note that the sperms swim towards the tube, i.e. they are attracted to the malic acid. It is believed that the *archegonium* (the little pouch that contains the egg) discharges malic acid and so attracts the sperms.

14. Notice dragon-flies and other insects "pairing". The male in each case is passing sperms into the female.

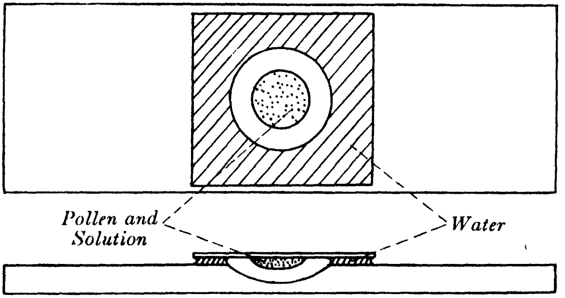


Fig. 143. Experiment with pollen in sugar solution.

15. Make a 10 to 20 per cent. solution of ordinary cane-sugar. Put a drop of this on a "cover-glass" and shake a little sweet-pea pollen into it (other pollen may do but sweet-pea has been found particularly successful). Invert the cover-glass over a hollow slide. Keep in a warm place and examine after an hour or two. You will almost certainly see pollen tubes of various lengths.

16. Examine prepared slides showing pollen tubes, sections of ovules, seeds, etc.

17. Open carefully a number of buds of a flower such as daffodil, tulip or pea. Cut out the stamens before they have started to shed pollen, without injuring the ovaries. Cover the remains of each flower with a muslin bag to prevent insects pollinating the flower. Divide the flowers so treated into two sets and after two or three days, pollinate one set with pollen carried from another flower of the same species, on a soft thin brush. Do the fruits develop in all cases?

18. Examine two or three insect-pollinated flowers and find out just how the pollen is transferred from stamen to insect and from insect to stigma (the arrangement as a whole is spoken of as the *pollination mechanism*). In the same way, examine self-pollinated and wind-pollinated flowers.

CHAPTER XV

GROWTH AND DEVELOPMENT

Growth

The power of growth is one of the most definite characteristics of living things, for all of them grow for at least the early parts of their lives. Anyone who has had young animals as pets or has kept a garden will not need to be *taught* this fact! The grass of lawns needs cutting every few days during the spring and summer, and giant sunflowers, sweet peas and other annuals grow to tall luxuriant plants in a single season. Clumps of perennials such as violets and Michaelmas daisies extend year by year and woody plants (bushes and trees) continue to grow as long as they have any life in them.

The stems of plants grow from masses of dividing cells in special *growing points* at their tips. At these growing points new leaves, and in many cases new flowers, are formed and additions made to the length of the stem. In the leaf axils (the angles between the stem and the leaves), new growing points arise though not all of them develop into new branches. Growing points and the young leaves (or flowers) developing from them are easily seen at the heart of a cabbage or brussels sprout or at the top of a hollyhock stem. Roots grow from similar growing points but these differ from those of the stem in that they are always protected by small root caps.

Woody plants usually protect their growing points for the winter by forming hard waterproof *bud scales* around them. From these *buds* growth continues each spring. In addition, the trunk, branches and twigs (and all parts of the roots) grow in thickness each year by the formation, by a special *cambium* layer (Fig. 84), of a new annual *layer* of wood and phloem just within the older phloem and outside the older wood. (The wood layers appear as *annual rings* when the tree is cut across because the spring growth is much softer than the summer growth each year.)

Most of the higher animals, including man, do not continue growing throughout their lives but grow only to a certain

Fig. 144. The opening of a horse-chestnut bud in spring. Note the developing twig, leaves and flower buds, the bud scales and (on the older part of the twig) leaf scars and lenticels.

[Photo: A. E. Ashby.]

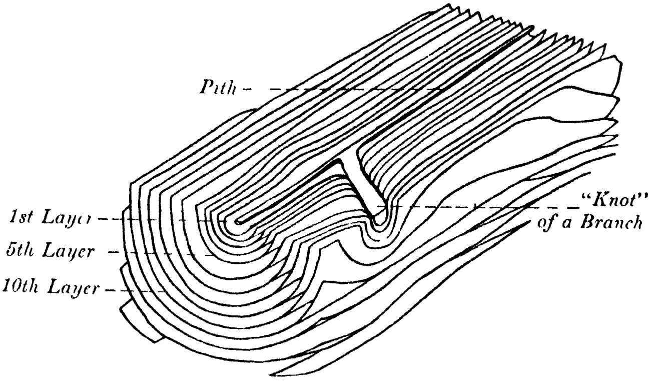


Fig 145 A small block of wood, drawn with the annual layers separated slightly from one another

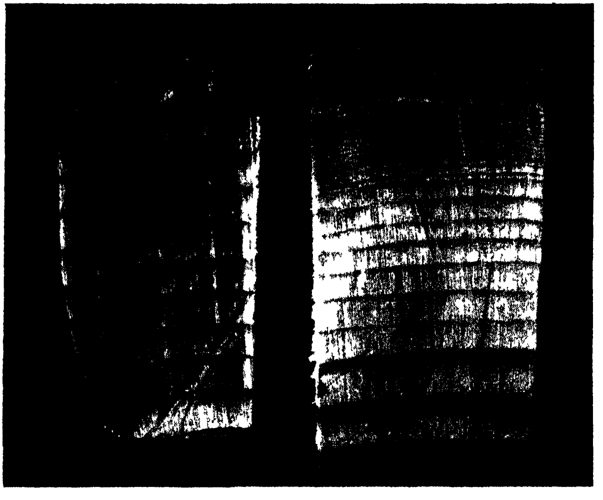


Fig. 146. Annual rings in spruce fir Notice the different widths of the rings: the section on the left was from a tree which grew in full daylight while that on the right was from a tree which, in its later years, had been in deep shade and so less able to carry out photosynthesis

[Photo: R D G]

"adult" size. Other animals, such as fish, grow continuously throughout their lives. In any case, the mechanism of growth is very different from that of the plant. Growth is not confined to certain special growing points and cambium layers but takes place in every single part and in such a way that the proportions of the whole organism remain approximately constant. The external skeletons which completely enclose crabs, insects, etc., present a serious obstacle to the growth of such animals. This difficulty is overcome by the animal *moulting* its skeleton periodically and swelling considerably after each moult before the new skeleton has had time to harden.

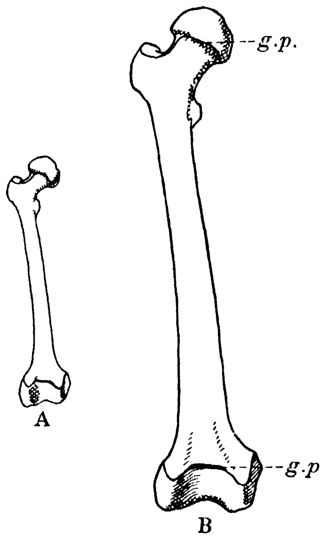


Fig. 147. Growth of a human bone (femur) - the relative sizes at five and fifteen years of age. *g.p.*, the growth pads, by the action of which the bone is lengthened.

Development

One remarkable feature of growth in living things is the power of *development* which accompanies it; i.e. the power of forming new parts and of increasing in complexity. As a plant grows, it is continually developing new branches, new leaves and new flowers, and anyone who has kept frog spawn or germinated seeds will realise that development is as least as obvious as mere increase in bulk in those cases.

Development is most important in the earliest stages of growth. At one time it was thought that the sperm carried an exact, but very minute, model of the adult and that the egg contained the reserves of food by which this model, by mere *growth*, increased in size. Now we know that neither the egg nor the sperm contains more than a little protoplasm and a nucleus. Thus, each living thing starts its *life history* from

a fertilised egg, i.e. from a single cell as simple as, or even simpler than, an individual Amoeba. While a newly formed Amoeba has merely to grow, other living things have to develop a whole range of organs before they can function successfully. Thus a plant needs to develop at least a small length of root and a leaf or two before it can live independently and an animal will need a very much more complicated set of organs. While these are developing and the living thing is too undeveloped to function independently it is called an *embryo* (see Figs. 137 F, 148 and 150 *a*). We are not surprised to find that an embryo rarely resembles the adult of its species and that its development usually takes place in the comparative safety of the ovule or of the egg.

Life History of the Flowering Plant

In the flowering plant, the ovule containing the egg cell (p. 232) develops for a while as a parasite on the parent plant. The ovary develops to give the *fruit* (p. 7) and within it the ovules develop into *seeds*. The fertilised egg-cell divides repeatedly to give a mass of cells, which gradually form themselves into an embryo plant and a food store. The walls of the ovule become the skin of the seed. The embryo is composed of a small root and a small shoot with one or two tiny leaves or *cotyledons*. In some seeds, the store of food is contained in the cotyledons (e.g. sycamore, mustard and broad bean); in others, it is in a special *endosperm* surrounding the cotyledons (e.g. castor oil and ash) or alongside the simple cotyledons (as in the cereals).

The seed, as we have already mentioned (p. 163), is capable of resting in a dry condition for long periods. It is during this time it may be scattered and so establish the plant in new areas (pp. 232–6).

Given a supply of water and oxygen and a suitable temperature, the seed begins to grow or *germinate*. For a time, it lives on its own food reserve. If this is in an endosperm, the cotyledons absorb it. The cotyledons may or may not come above ground and act as the first leaves of the embryo plant.

When the roots are well established and the first leaves opened in the light the young plant is capable of carrying on photosynthesis and so of feeding itself. Then it is no longer an embryo but a fully functioning seedling well started on its life story.

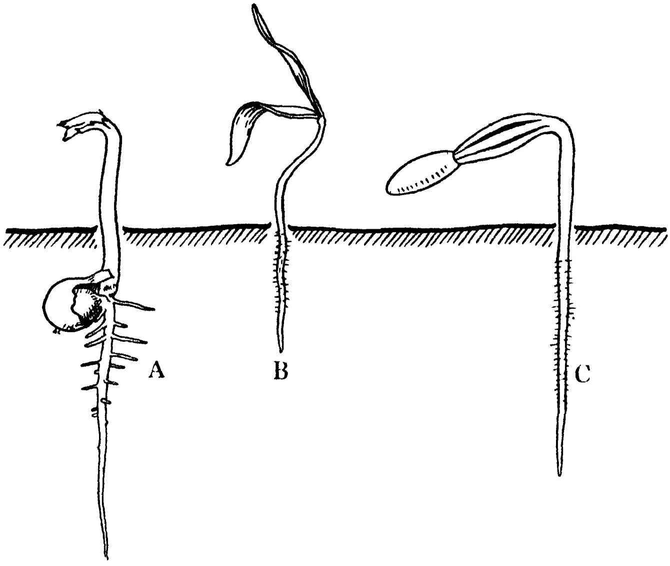


Fig. 148. Germination of seeds. A, Pea: cotyledons remaining underground. B, Sycamore: cotyledons acting as first foliage leaves. C, Pine: cotyledons absorbing food from endosperm; later they spread and become the first foliage leaves.

Animal Life Histories

We may take the development of the frog very briefly as an example of a simple animal life history: the outline is familiar to all who have interested themselves in studying living things. The fertilised egg is surrounded by a protective layer of jelly and consists of an upper black half, which is mainly protoplasm, and a lower white portion, which is mainly food store or yolk—the whole constituting a single cell. The first process in development is the mere division of this one cell into a large

number, often over a thousand, small cells and the formation of a cavity within them. Next the black mass of cells at the top begins to grow downwards as a double layer over the yolk cells until the yolk is almost completely enclosed in a double-layered sphere.

It is from this point that the development of the organs really begins and while this is taking place, the embryo tadpole elongates, first to the shape of a bean and then to that of

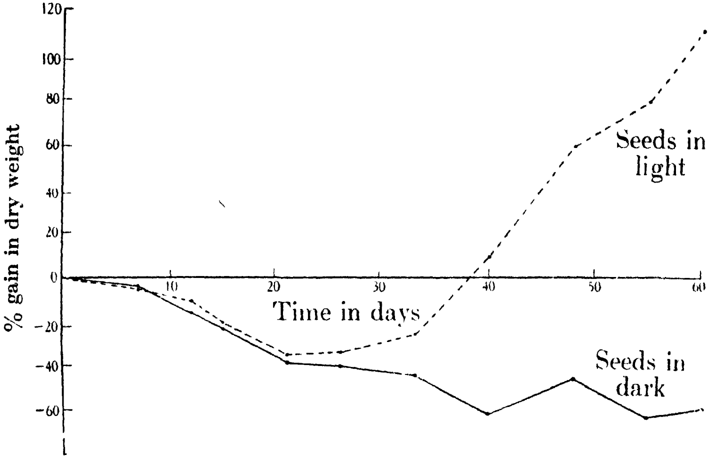


Fig. 149. Graphical records of the changes in weight of germinating peas, some grown in light and others in darkness. "Dry weight" means that all water in the seeds and seedlings was expelled by heating for some hours to 100° C. What can you deduce from these records? (Data from experiments carried out at McGill University, Montreal.)

a comma. The inner of the two layers is the rudiment of the food canal and this, together with the liver, gradually develops from it. Most of the outer layer is destined to form the skin but a strip along the centre of the back becomes thickened and its edges roll up so that they meet along the middle of the back and form a tube. This, the neural tube, is the beginning of the spinal cord and the front end of it swells up and develops into the brain. Eyes and ears develop partly as outgrowths of

the brain and partly from the adjacent skin of the head. Between the neural tube and the food canal there develop the kidneys and the notochord - the latter is a rod of turgid tissue on which the backbone is built. Below the front of the food canal, a number of cells unite to form a tube which bends into

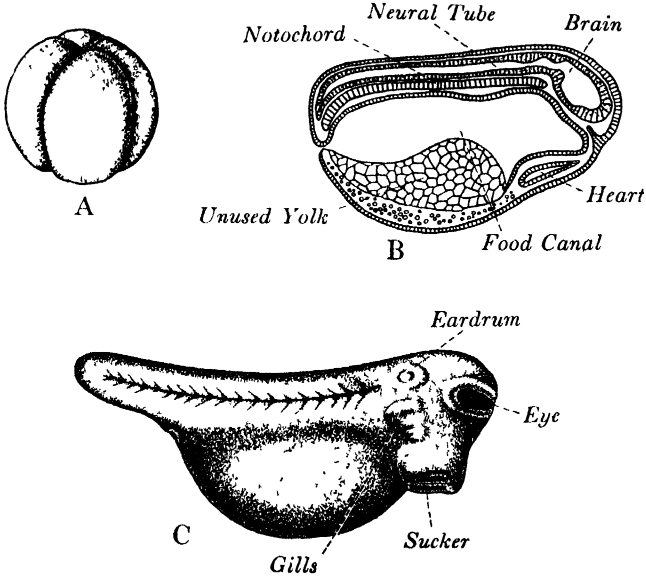


Fig. 150 *a*. Development in the egg of the frog. A, An early stage in cell division. B, Section showing that the first rudiments of the various organs have been completed at the bean-shaped stage. C, The embryo in the state in which it hatches.

an S-shape, divides into chambers and so develops into the heart. Similarly, other cells in the body form tubes which join together to form the blood vessels, while cells adjacent to the notochord become gathered into blocks from which the main muscles are derived.

These changes result in the general plan of the main organs being laid down—their positions are marked out and the material for each of them is set aside—but they do not *work*

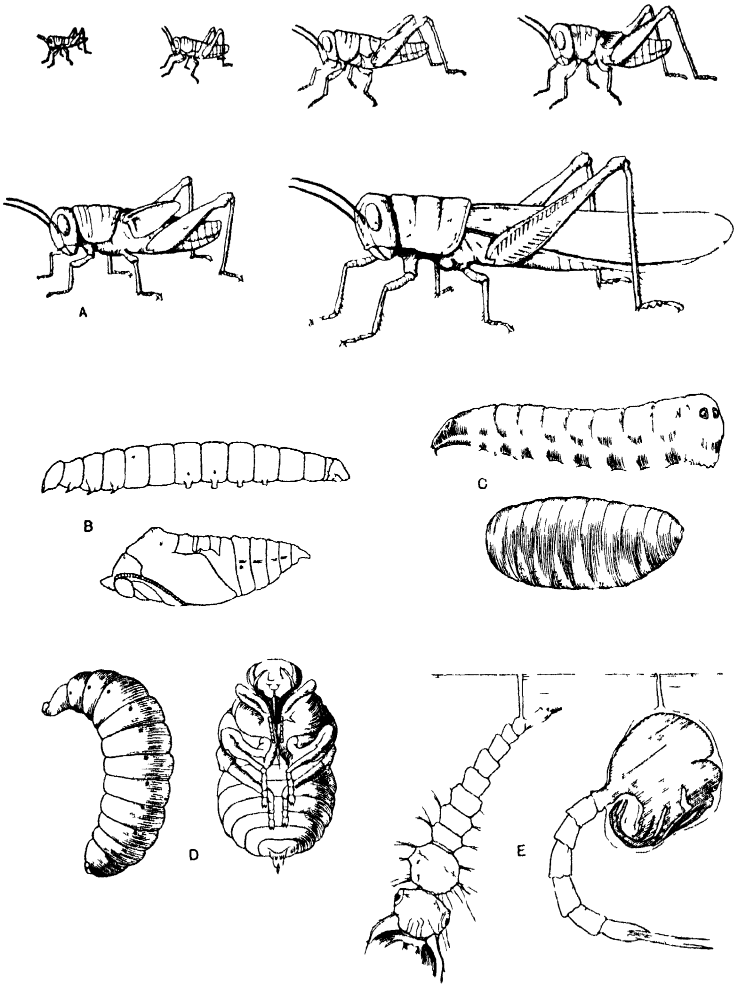


Fig. 150 *b*. Insect development. A. The six instars of a grasshopper: note the rudiments of the wings in the fourth and fifth nymphal instars. ($\times 2$, in each case).

Larvae and pupae of (B) butterfly, (C) a house-fly, (D) a bee and (E) a mosquito gnat. (Various scales.)

for practically all the cells are still composed of protoplasm similar to that of Amoeba. Before the parts of the body can function, the cells must become differentiated. To take but one example, the embryonic cells of the neural tube must develop the long fibres which will make them real nerve cells. When this phase of development is concluded, the animal is in a condition in which it can shift for itself and is no longer an embryo—and it hatches as the *larva*[1] which we call a tadpole.

Some further development takes place during the life of the animal as a tadpole but such development is of minor importance when compared with the hundred-fold increase in bulk which is brought about by growth.

Metamorphosis takes place when the tadpole is about three months old. Externally, it involves the development of legs and the loss of the tail, the enlargement of mouth and eyes and changes in shape and colour. Equally profound changes take place within the animal: lungs develop and the gills disappear, the food canal is shortened, the liver and pancreas undergo further development and the brain and skeleton are greatly modified. The small frog which results from these changes is no longer a mere aquatic larva but can live equally well on land or in water. It feeds by catching insects and grows up to adult size in two or three years.

The majority of eggs develop into young animals which closely resemble their parents. Insects which show such *direct development* include, among others, dragonflies, mayflies, cockroaches, bugs, earwigs and grasshoppers. As we have mentioned (p. 242), growth in insects cannot be continuous because of the hard outer skin: increase in size takes place mainly at the periodic moults in the short time which elapses between the shedding of the old skin and the hardening of the new. Each stage of the insect's life—that is, between one moult and the next—is called an *instar*. The earlier instars of insects which show direct development differ from the adult only in size and in the absence of wings: the latter develop in the later instars but cannot, of course, function until they are

[1] The word "larva" is used of a young animal which differs very much from the adult form—so that it has to undergo, later in life, a radical development change known as a *metamorphosis*.

fully formed as a result of the final moult. Such young insects are not really larvae: they are spoken of as *nymphs*.

Many insects (butterflies and moths, flies, gnats, beetles,

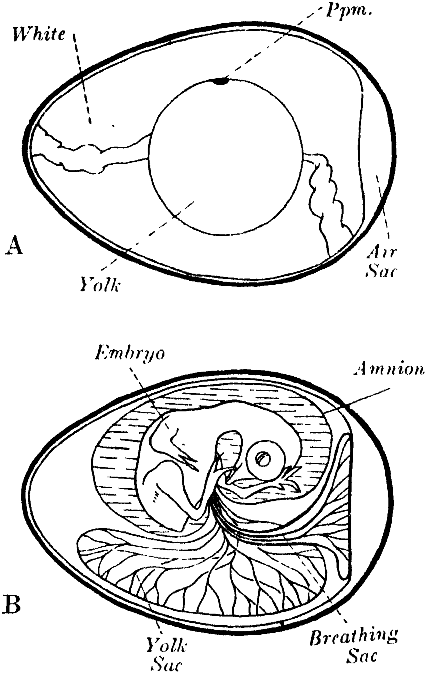


Fig. 151. The development of the chick. A, Egg when laid. B, After incubation for 14 days.

bees, etc.) show an *indirect development* to an even greater degree than the frog. In these cases, the larva is a very poorly developed worm-like caterpillar or maggot and this feeds enormously and grows rapidly. When the larva has grown to its full size, it changes to the adult form, but the changes are so great that the insect has to pass through a special resting stage (called the *chrysalis* or *pupa* stage) while it is undergoing them. We might almost say that the animal is "closed for alterations".

The Food Supply of the Embryo

Such special growth stages are not necessary when the amount of yolk is very large, and this condition is found in birds. In a new-laid hen's egg we find a very large yolk and also the jelly-like "white" which acts as a reserve of water and a shock absorber for the very delicate embryo. The protoplasm is at first a tiny *germinal disc* floating on the yolk, but

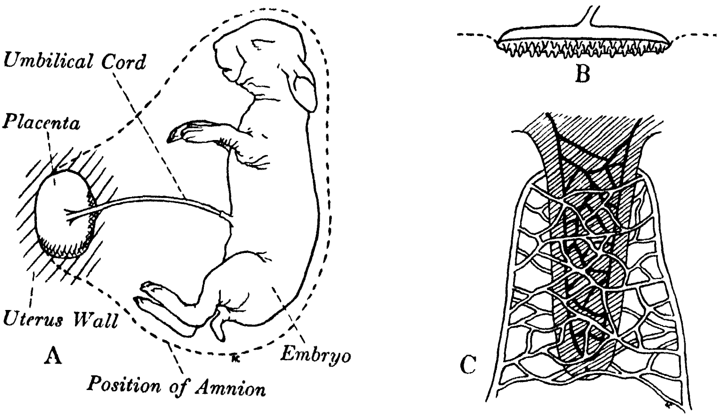


Fig. 152. The food supply of the mammal embryo. A, The embryo attached to the uterus wall. B, The placenta, drawn to show the villi. C, Capillaries within and around a single villus.

when the egg is kept warm by the hen or in an incubator the protoplasm begins to develop at the expense of the yolk. It not only begins to form the embryo chick but grows a *yolk sac* —a skin rich in blood vessels which gradually surrounds the yolk and absorbs the food --and also sends a *breathing sac*, bearing an artery and a vein, down to the skin of the air sac at the end of the egg and this then acts as a sort of "external lung" for the chick.

The mammals have evolved an even better method of feeding and protecting the developing embryo—a method very similar to that by which the ovules of flowering plants are fed and protected. The egg is microscopically small and has no food

supply in itself, but it is retained within the body of the mother in the uterus (Fig. 136) and draws all the food it requires from the blood of the mother. As in the case of the chick, the fertilised egg not only develops the embryo itself but other things. We find that after a while the embryo is surrounded by a skin called the *amnion* and that this is filled with liquid so that the delicate embryo floats protected within its own "private pond". In addition an artery and a vein which together constitute the

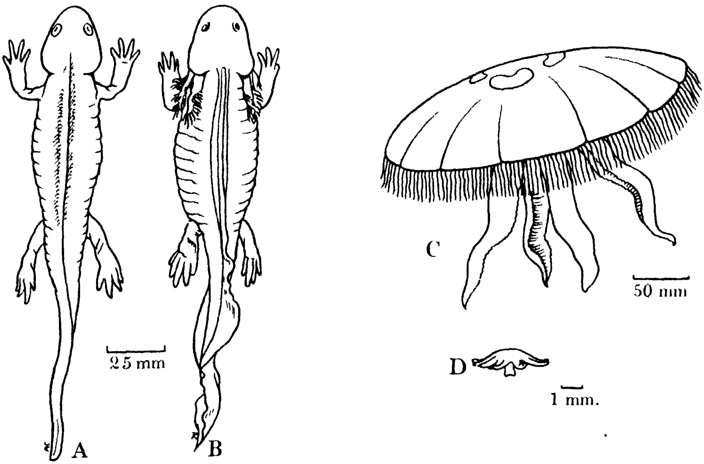


Fig. 153. Backward development. A, *Amblystoma* —and B, larva ("Axolotl"). C, Jellyfish —and D, larva.

umbilical cord grow out from the embryo, and fixing themselves to the wall of the uterus, form a *placenta* there. This is a thick circular piece of flesh, from the underside of which a large number of *villi* grow into the actual substance of the uterus wall. Both the villi and the uterus wall contain masses of capillaries and while no blood actually flows from mother to embryo the blood of the latter, kept going by its own heart, takes in food and oxygen from the mother's blood and gives up carbon dioxide and other waste matter. Thus the embryo is able to develop as a parasite on the mother and can draw upon a food supply quite adequate for all its needs. It develops

in comparative safety and in many cases (e.g. guinea-pig) to such a degree that the young animal is almost sufficiently well developed to fend for itself within a few hours of being born.

"Backward" Development

We have stressed growth as a progressive increase in bulk involving, usually, progressive development, but we ought not to leave the subject without pointing out that development is not necessarily always progressive. In the metamorphosis of tadpole to frog, not only do new features develop but old parts, such as tail and gills, shrivel up and disappear. In Mexico there lives an animal similar to a large newt tadpole. It is actually the tadpole stage of a newt-like animal *Amblystoma*, but normally it changes to the adult only if the pond in which it is living dries up. The remarkable thing is that, if during the early stages of its metamorphosis the pond becomes full again, it will reverse the process and "develop backwards" to its original stage.

An example of the same process in a more familiar creature has been provided by experiments on the common jellyfish. When this animal is starved it does not die but lives on its own body-substances and so gradually becomes smaller. As it does so it not merely diminishes in size, but develops *backwards* through the various stages of its growth, losing its adult characters and regaining those of its larval stage, and finally arriving at the state from which it started its development! If it is then given food again it will "grow up" once more and by alternate feeding and starving the animal can be induced to grow up and "develop backwards" many times.

"Regeneration" and Healing

The power of growth and development is never completely lost in a living thing. We have pointed out that plants (and some animals) never finally "grow up"; but, even in those animals which grow only to a certain adult size, powers of growth remain. Throughout life, the cells of every part of the body go on multiplying in a regular manner, the new cells taking the place of the old. While health remains, this process

Fig 154 Healing at the end of a broken branch of Douglas Fir, external appearance on the right and section on the left Note that both new wood and new bark have grown The results of the same process can be seen at the sides of the wound in the tree pictured in Fig 70

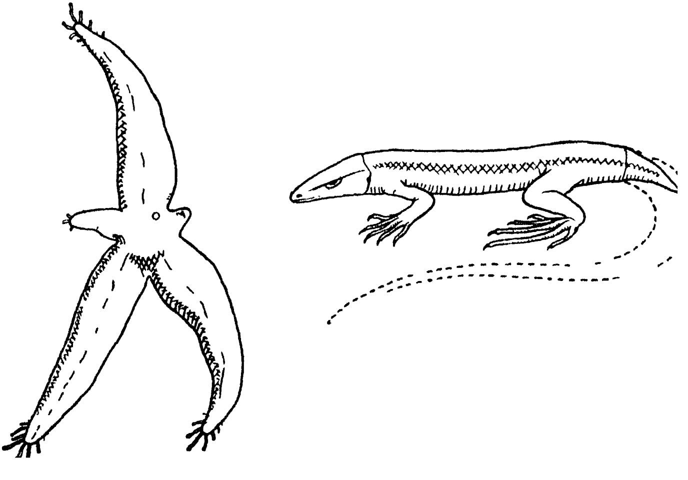


Fig. 155. Regeneration in starfish and lizard

goes on in such a way that the various parts are continually being renewed and rebuilt. Where parts are damaged by accident or disease, the same powers of growth are responsible for repairing and, in some cases, even for regrowing (or *regenerating*) lost parts of the body.

We are familiar enough with healing processes in our own bodies: a broken bone, a surface cut or wound, or diseased parts of the body repair themselves. In the same way a tree

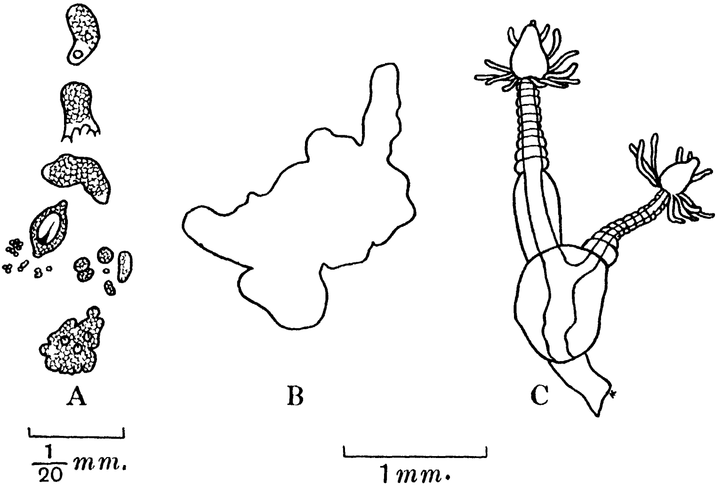


Fig. 156. Regeneration in *Pennaria*. A, Some of the isolated cells. B, Mass of cells after a day or two. C, New polyps growing after 6 days. [After H. V. Wilson.]

repairs even quite deep cuts in its bark, new bark (and new wood also, if necessary) growing in from the sides (Fig. 70).

Plants and many lower animals can go beyond mere healing and actually replace lost parts. If we see a tree with its branches "lopped" (cut back almost to the trunk) we might be forgiven for supposing that such treatment would have killed it: on the contrary, a mass of new twigs grows out from the cambium of each cut end. The regeneration of a "pollarded" willow is an extreme example of this.

Among animals, we find that starfish which have had one or more arms torn off regenerate the missing parts—even one solitary arm can regenerate the remaining four. Lizards when caught by the tail can break away, leaving the tail behind, and grow a new tail. Similarly, a crab or lobster can cut off legs or claws which are caught or damaged and gradually replace them. If an earthworm is accidentally cut in two it does not necessarily die: under favourable conditions the head end grows a new back portion and (what seems even more wonderful) the back portion grows a new front end!

We could add very substantially to this list but one final example will serve. *Pennaria* is a small animal living in the sea and consists of a number of polyps, rather like a number of tiny sea-anemones or coral polyps, on a stalk. Like all other living things above the size of Amoeba, it is composed of a large number of individual cells. One scientist tried to find out what would happen if he separated all the cells from one another, and to do this he pressed the animal through a very fine silk sieve. The result was that the isolated cells gradually came together again to form a solid mass and in a few days had regenerated new polyps!

The Characteristics of Living Things

It will be convenient here to summarise those characteristics which distinguish living organisms from those things which are not alive.

First of all, living things feed and grow—and they can feed on substances other than their own protoplasm, changing them as may be necessary and assimilating them into their own bodies. (Crystals, of course, can grow although they are not alive but they can "feed" only on the substance which is actually concerned in the growth.) Associated with this power of growth, there is usually the power of development, and to a very great extent living things can heal their wounds and regenerate lost parts: non-living things have no such powers. Again, only living things can reproduce their kind.

Finally, living things have the faculty of responding to stimuli. As we have pointed out, in these days of complicated machinery actuated by the mere pushing of a button, it is

necessary to add that such responses are normally of value for the survival of the organism or of its race. Most of the responses are movements and so we can add that living things can move to some extent—if the organism does not move as a whole, some of its parts or its protoplasm may do so. Such motion, unlike that of a boulder falling down a mountain side or of the stars in their courses, is under the control of the organism itself—as is the release of the energy necessary and the excretion of waste materials.

PRACTICAL WORK

1. Watch the growth of children and young animals. Express the monthly increase in height (or weight) as a percentage of the total height (or weight) at the time and make a graph of the percentages and notice how they vary. You should be careful (particularly if you are measuring by weight) to take your records at corresponding times, e.g. before breakfast in each case.

2. Watch the growth of plants. Make records of the growth in height of individual plants. Record the growth of a root and find out where its growing region is by marking equal intervals on it by means of a thread wetted with Indian ink, and leaving it for a day or two under conditions suitable for growth, e.g. in a glass jar lined with damp blotting paper. A bean, pea or sunflower seedling with a straight root about 2 in. or 3 in. long is suitable. The same experiment can be carried out using stems, e.g. young dandelion stalk or a bean seedling with a stem about 3 in. long.

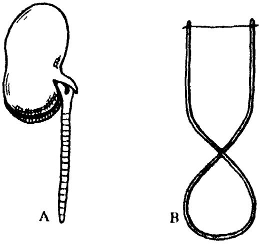


Fig. 157. Experiment on growth of bean root. A, Root marked at beginning of experiment. B, Wire frame and thread for marking.

3. Watch carefully the opening of winter buds on trees. Notice the *girdle scar* left by the bud scales in horse-chestnut, beech, etc. On older twigs trace the amount of growth year by year by means of these scars.

4. On an actively growing plant notice the development of new leaves and flower buds from the growing points at the tips of the stems. Pick a brussels sprout or lettuce to pieces, leaf by leaf, and find the growing point at the heart.

5. Soak various seeds in water for 24 hours; then dissect them to see the details of their structure. Examine microscope sections of maize or other seeds. Embryo plants can be seen well in ash and sycamore fruits.

6. Watch the germination (on soil or on flannel in a saucer or in a jam-jar) of various seeds, e.g. pine, horse-chestnut, acorn, sycamore, bean, pea, mustard. Notice how the root and shoot appear and what happens to the cotyledons and endosperm (if any). After the seedlings have passed the embryo stage, transplant them to the garden and watch their further growth.

7. Take a number of seeds (not all of the same species) and divide them into five approximately equal sets. Put each set into a small jam-jar with cotton-wool but vary their conditions as follows:

(*a*) No water at all.

(*b*) Well cover the seeds with water which has been boiled to expel all the air it contains.

(*c*) Keep the cotton-wool well wetted without keeping the air away from the seeds altogether.

(*d*) Keep the jar in a dark cupboard with the cotton-wool moistened.

(*e*) Keep the jar, with seeds moistened, in a cold place—preferably where the temperature is only just above 0° C. (Keep all the others in a much warmer place.)

8. *Seed-testing.* Take two plates of equal size and nearly fill the lower one with clean sand. Cover this with cheese cloth or blotting paper and place a number of seeds e.g. 100 on it (if possible, they should not touch one another). Then cover the seeds with another piece of blotting paper or cloth, wet the sand, etc., till saturated and invert the second plate over it. Notice the percentage of seeds which germinate: a week or so is usually sufficient. Fresh sand and paper should be used for each test or fungi will develop in them.

9. Collect frog spawn and follow the development of the tadpole and its metamorphosis to frog. (In order to see the details of a developing egg, remove the jelly with scissors and mounted needles.) Fish spawn may be bought from dealers and its development followed. Hatch the eggs of "silkworms" or other moths or butterflies and follow their life history. The larvae (and sometimes the eggs) of mosquitoes and gnats can be collected from stagnant water and their life history studied.

10. (*a*) Break a new-laid hen's egg into a basin and notice, if the egg has been fertilised, the small brown disc of protoplasm within.

(*b*) Take an egg which has been incubated for two or three days and lay it down *almost* immersed in water at about 104° F. Carefully remove a circle about 1 in. in diameter of what is then the top of the shell and examine the embryo within.

(*c*) Peel part of the shell of an egg which has been incubated for about a fortnight and examine the embryo chick, the yolk sac, and the breathing sac.

11. Examine an embryo of a rabbit or other mammal.

12. Study examples of healing and regeneration such as we have mentioned in this chapter—and any others which you find. Cut off the crown of tentacles from a living Hydra and the leaves from a large dandelion plant: watch for regeneration.

CHAPTER XVI

BACTERIA, DISEASE AND HEALTH

The word "health" is derived from an old Anglo-Saxon word which means "harmony" and by perfect health we mean the full and perfectly harmonious functioning of the various parts of the organism. This means far more than the mere avoidance of disease. There are in schools pupils who are content to work just well enough to escape being punished for laziness but there are others who show more energy, take a real interest in their work and "just naturally" try to do their best. Similarly, there are large numbers of people who are content if they pass through life without suffering from any of the major diseases while there are others who are not merely well all the time but seem to be literally "bursting" with good health. Such people are usually looked upon as abnormally fortunate. Modern science, however, believes that such a high degree of vigorous health and vitality could be the lot of practically every one of us and should be regarded as normal by the community.

Certainly the majority of cultivated plants and domesticated animals, if given good conditions and properly looked after, enjoy remarkably good health. There is no reason, however, to suppose that there is anything very surprising in this or that man, alone among living organisms, need accept a low standard of health.

BACTERIA

Bacteria are the smallest visible forms of life:[1] most are between 0.001 and 0.01 mm. in length. They vary considerably in shape and some of them are able to swim about by means of

[1] **Viruses are agents of disease which are much smaller than bacteria: they are invisible to the human eye with even the most powerful microscope, though they can be photographed with the electron microscope. They are responsible for carrying colds, influenza, mumps, smallpox, distemper in dogs, foot and mouth disease in cattle, etc.**

cilia. They have no apparent internal organs, and seem to be merely protoplasm within a cell wall. Naturally, such living things have to live in a liquid of some sort (p. 132) and it is

Fig. 158. Diagram to show shapes of various disease-producing bacteria. A, *Staphylococcus*, and B, *Streptococcus*, produce inflammation and blood poisoning. C, Typhoid bacillus. D, Cholera bacillus. E, Plague bacillus. F, Tetanus (lockjaw) bacillus (the round bodies are spores). G, Anthrax bacillus. H, Tuberculosis bacillus. I, Diphtheria bacillus. J, Pneumonia coccus. ($\times 4000$.) [Campbell.]

from the liquid that they take in food by absorption. As they feed they make more and more protoplasm and so grow.

As with Amoeba, growth does not go on indefinitely but at a certain size—different for each species of bacterium—the individual divides into two and so two new bacteria are formed. When food is plentiful this may happen two or even

three times in an hour and so multiplication can proceed very rapidly. Even if a collection– or *colony*—of bacteria doubled its numbers only once an hour, it would mean approximately a ten-million-fold increase in a day. Actually food shortage and the accumulation of waste products soon put a stop to such rates of multiplication, but it is unfortunately true that the blood and lymph of the human body, by supplying food and warmth, give some bacteria almost ideal conditions.

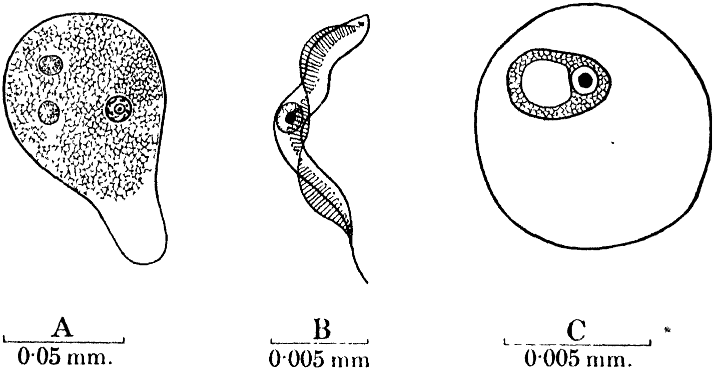


Fig. 159. Other microbes. A, *Entamoeba*, a parasite related to Amoeba, causes dysentery. Notice the nucleus and two ingested blood corpuscles in this specimen. (×250.) B, A Trypanosome, a type of parasite which causes sleeping sickness and certain animal diseases in the tropics. Notice the nucleus and "undulating membrane" of protoplasm, by means of which it swims. (×2000.) C, A malarial parasite living within, and feeding upon, a red corpuscle. (×3000.) [A and B after Borradaile.]

Unfavourable conditions, on the other hand, do not necessarily mean the death of the bacteria. If the food supply fails, most bacteria form spores and in that condition can be blown about from place to place by air currents and can live for a very long time, returning to active life again when reaching suitable conditions. At temperatures near or below 0°C. bacteria are inactive but they are not killed. Heat, however, can be fatal to them. Bacteria themselves are killed by a temperature of about 80°C. but the spores need to be subjected

two or three times to temperatures above the boiling-point of water. Certain chemicals which we call *preservatives* and *disinfectants* also kill bacteria—and so does bright sunlight.

The importance of bacteria to us and to other living things lies in their power of carrying out all sorts of different chemical changes, i.e. making one substance from another. We have already referred (p. 126) to the way in which the bacteria of the soil form ammonium salts and nitrates from humus: the similar bacteria which turn sewage to a harmless mixture of water, ammonia and carbon dioxide are equally useful to us. Lactic bacteria, which make lactic acid from the sugar in milk and so turn the milk sour, are regarded as useful by the cheesemaker but as a great nuisance by the housewife. On the other hand, many bacteria are very definitely harmful and among these the bacteria of disease are the most important.

Very similar to bacteria—which are regarded as plants—are microscopic animals such as those which cause malaria and sleeping sickness. The word "microbes" is often used to include both these and bacteria.

Disease

If we own a bicycle or motor-car or a wireless set we know that there are all sorts of things which may go wrong with it. Some of these mishaps mean that it works less efficiently while others are serious enough to stop it functioning altogether. The same is true of human bodies—or for that matter of all other living things. Anything which goes wrong with the working of any part may be called a "disease".

By no means all diseases are due to bacteria and other microbes. Many are due to other causes. We have already spoken of deficiency diseases, e.g. those due to lack of certain salts (pp. 93 and 133) and of the various vitamins (p. 91). Again, diseases may be caused by the failure of various organs to function properly. For example, diabetes is due to the failure, for reasons at present unknown, of part of the pancreas (not the part which makes the pancreatic juice). As a result, the pancreas ceases to make a hormone known as *insulin*, and in the absence of this the liver fails to store sugar and too much is left circulating in the blood.

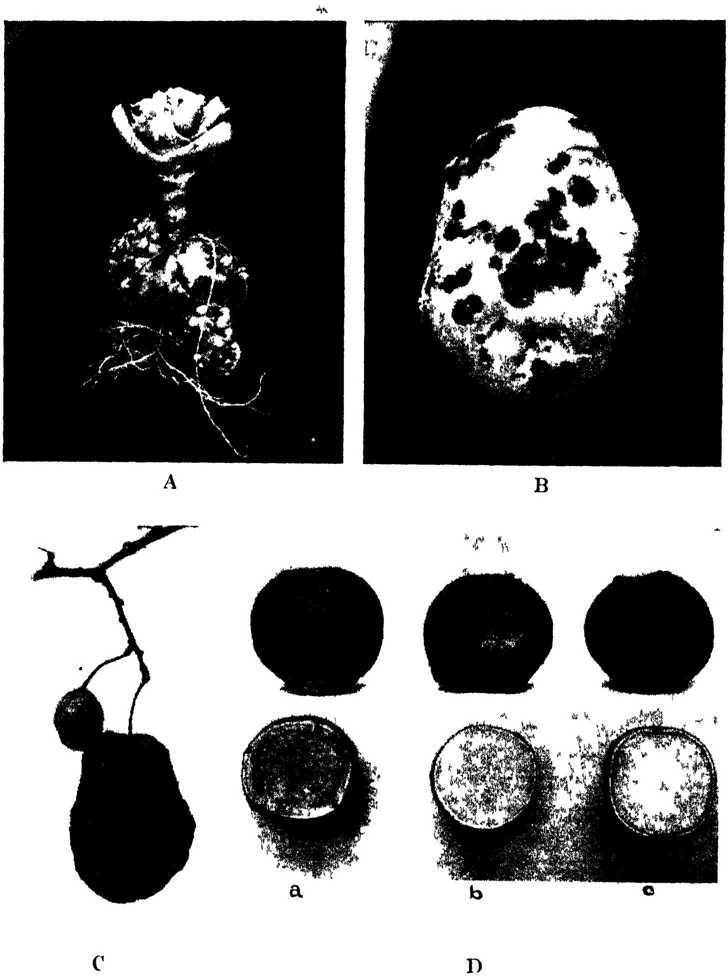


Fig. 160. Diseases of Cultivated Plants. A, "Club-root" in Cabbage. B, "Corky scab" in Potato. C, "Bladdered plum" (or "plum pocket"): a healthy plum is shown on the left. D, "Brown-heart" in Swedes (whole swedes above and sections below). The left-hand pair are suffering from the disease but the others are free of it.

[Photos: D, Prof. J. G. Coulson: others, R.D.G.]

On the opposite page we have illustrated a number of plant diseases due to various causes. The corky scab on the potato is caused by bacteria, the bladdering on the plum by a fungus and the club-root of the cabbage by a fungus-like organism called a *slime-mould*. The brown-heart of swedes is a disease very common in Quebec and is thought to be due to a deficiency of boron compounds in the soil. There is some doubt about this but there is no doubt that swedes grown in pots of sand do develop brown-heart unless watered with water containing a small amount of boron compounds. Those shown in our photograph received solutions of the following concentrations: (*a*) ½ part per million; (*b*) 1 part, and (*c*) 2 parts per million. It will be noticed that brown-heart developed only in the first case.

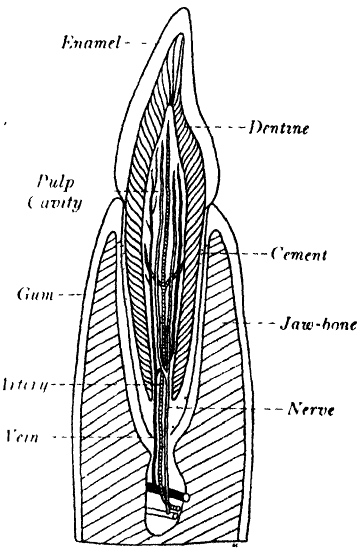


Fig. 161. Section of a single tooth. (The finer branches of the blood vessels and nerves are omitted.)

Even where bacteria are responsible for disease, their bad effects are usually due to the chemical substances they produce rather than to direct damage to the tissues or to the absorption of food. The decay of teeth is a good example of this. The section shown in Fig. 161 gives a good idea of the structure of a tooth. The *enamel* is a very hard compact substance, rather liable to be cracked by hot or cold foods, while the *dentine* is soft and very porous: both contain a large proportion of calcium carbonate and calcium phosphate. Lactic bacteria settle in the food which lodges on and between the teeth and in the cracks in the enamel—and make lactic acid. This acid gradually dissolves away the calcium salts of the enamel and

dentine until, if not prevented, decay reaches the *pulp* and there causes toothache. Again, the bacteria of diphtheria

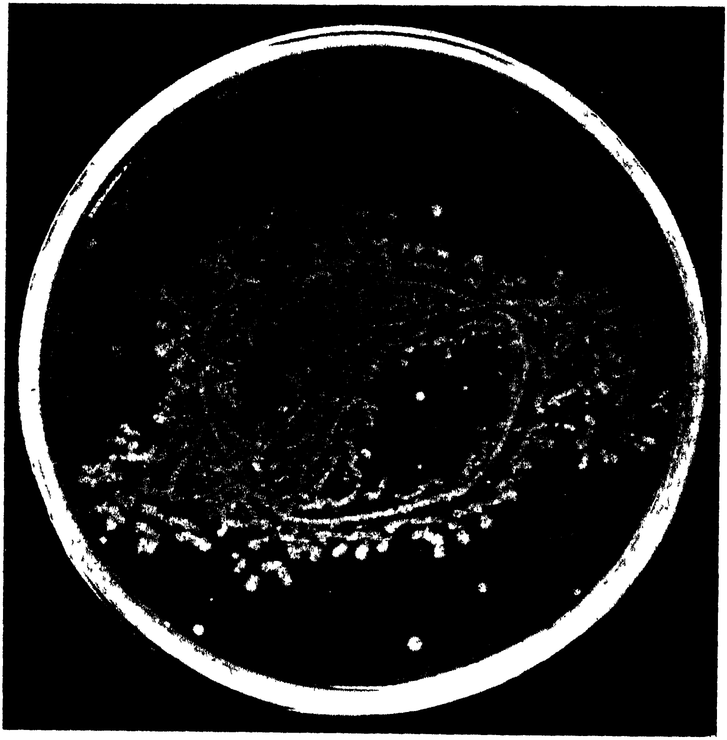


Fig. 162. A fly was allowed to walk about on the agar jelly in this Petri dish (see Practical Work, § 8) and the dish set aside. The colonies of bacteria, seen in the photograph, developed—showing how efficient a carrier of bacteria a fly can be. [From Hewitt: *The House Fly.*]

settle in the throat and excrete substances which not only cause inflammation there but also have very serious effects on the heart and kidneys. Most other disease bacteria act in much the same way.

Fig. 163. Bacteria may also be carried on our boots This photograph shows a tray of disinfectant at the entrance to the Ovaltine Farm: everyone entering is required to rub his boots in it so that no living bacteria are carried in on them. [Photo: A. Wander & Co , Ltd.]

Transmission of Disease Bacteria

A person suffering from an "infectious" disease—e.g. diphtheria, measles, colds—has a very large number of the microbes concerned living in the liquid which bathes the mucous membrane of the nose, mouth and throat. Every time he coughs or sneezes, and to a less extent in talking and normal breathing, he expels into the air around him a spray of fine droplets of the liquid, each droplet being charged with some of these microbes. If any other person is so near that he breathes the same air—and this is often the case in crowded, stuffy places—that person naturally breathes the germs in also. Many people catch colds, etc., simply because someone else coughs at them in a crowded bus or train when their bodily defences are not as efficient as they should be.

If bacteria do not find another host in this way, they sooner or later form spores and settle down with other dust particles. Hence, it is quite safe to assume that where there is dust, and especially where that dust is stirred up by brushing or by people walking about on it, there is danger from bacteria. Experiments have shown that the air at sea or on a mountain rarely contains an average of more than one or two bacteria per cubic metre. In a crowded, badly ventilated room there may be many million per cubic metre and, while adequate ventilation reduces their numbers considerably, there are always large numbers of bacteria in the air of a room where people are crowded together.

Another way in which a person may transmit bacteria is by licking the finger to turn over the pages of a book. This action leaves bacteria on the edge of the page and the next person to do the same thing with the same book removes some of the bacteria to his mouth. Kissing on the lips, too, is often responsible for transmitting bacteria and wise parents to-day refrain from kissing their children, especially babies, in this way. In fact, in some nurseries adult visitors are expected to wear antiseptic pads over their mouths and noses—and there would be an enormous improvement in the national health if all sufferers from colds and coughs were made to do the same whenever they were in the presence of other people.

PREVENTION AND CURE OF DISEASE

The day has gone when doctors relied mainly on bottles of medicine and we now have various methods of attacking disease. Where the disease is due to some known cause other than bacteria it may be possible to remove that cause. Thus scurvy and rickets, which are due to a diet deficient in certain vitamins, can be cured by means of diets containing those substances. Similarly in diabetes the *symptoms*, at least, may be removed by administering insulin prepared from animals. (In such a case we can scarcely say that the disease is *cured* for we are merely making up for the body's deficiencies: the organ concerned does not start to work properly again and the symptoms return immediately the treatment is discontinued.)

Medicines are often of value in dealing with a microbe disease—e.g. quinine definitely kills the microbes of malaria at a certain stage in their life cycle, salvarsan is a specific cure for sleeping sickness, and the more recent sulphonamides (popularly known as M. and B.) and penicillin are drugs that kill a wide variety of disease bacteria within the body —but normally medicines can do little beyond helping the body itself to recover. A broken leg can scarcely be called a "disease" but it will provide a useful parallel. The doctor can set the leg, fix it in splints and examine it occasionally to make certain that it is progressing properly but it is the living bone itself which must carry out the repair. So also, it is the body itself which has to do most of the work in recovering from a disease, the doctor seeing that it has the best conditions for the struggle.

THE BODY'S DEFENCES

In combating bacterial disease our first line of defence is to avoid infection. Our second, and usually extremely efficient, line of defence lies in our white corpuscles. These are present mainly in the blood (see p. 139) but are found also on the mucous membrane which lines the throat and nose (places which are very liable to infection by bacteria). As far as possible all bacteria are eaten by these white corpuscles, which move and feed in much the same way as Amoeba does

(Fig. 88). Of course we may from time to time "catch" more bacteria than our white corpuscles can deal with. Also, our white corpuscles are less numerous and less vigorous when we are in poorer health than usual.

In those cases in which bacteria do gain a hold and make us ill by producing their poisons or *toxins*, the body has yet another method of attacking them. It has the power of learning to make *anti-toxins* which render the toxins of the bacteria harmless. Thus the body is able gradually to recover from the disease and what is also very important is that in many cases the blood continues to make these anti-toxins for some time afterwards and so renders the body *immune* to further attacks of that particular disease. (You will probably know that we do not usually catch certain infectious diseases twice.) Such *natural immunity* may be gained by injection of dead bacteria or the bacteria of a milder form of the disease. Thus *inoculation* against typhoid fever is carried out by injecting dead typhoid bacteria, and the better known *vaccination* against smallpox consists of introducing the virus of the related but practically harmless cowpox into the blood by rubbing it into a series of fine cuts in the skin. In either case the appropriate anti-toxins are made and immunity is obtained.

Immunity can also be transferred from one person or animal to another by transferring some of the blood. A horse can be made immune to snake poison by repeated small injections. If, then, some of the blood is withdrawn and allowed to clot, the clear liquid, or *serum*, may be kept for as long as ten years and used as an antidote for cases of snake-bite poisoning. When a person is bitten by a poisonous snake, the appropriate serum, if available locally, can be injected into him and the anti-toxins will neutralise the snake poisons. In the same way anti-diphtheria and anti-tetanus serums can be prepared and used to give an *acquired immunity* to people who are likely to be exposed to infection[1] or even to those who are in the early

[1] There have been a number of cases in recent years of towns in the north of Canada being isolated by heavy snowfalls and threatened by epidemics—and then being able to check the spread of the disease by serums carried to them by aeroplanes.

stages of the disease concerned. Diphtheria immunisation has completely banished diphtheria from certain towns in Canada and U.S.A., and the same results will accrue in England when a sufficiently high proportion of children are immunised each year.

Health

In writing this chapter, we have laid the main emphasis so far on disease, but we must now point out that the whole point of view of science is changing and the modern attitude is to lay the emphasis on *health* rather than on disease and on prevention rather than on cure.

"Prevention is better than cure" we say. This is certainly true of disease— and, we would add, prevention is very much easier. Most disease *is* preventable and one of the biggest factors in prevention is the natural power of resistance of a thoroughly healthy body.

Usually people who fall ill are regarded as the victims of "bad luck" and, while this is true in some cases, we are coming more and more to believe that it is not easy for disease to gain a hold on thoroughly healthy people. Where disease does become manifest, it is usually because the body has gradually (often over a period of years) had its resistance worn down until it is too weak to fight infection. Illness is not so much a mere chance calamity which may well overtake anyone at any time and without apparent reason, but is rather the final result of a prolonged period of imperfect health.

The real reason why there is so much disease in the world is not so much the presence of bacteria as other more general causes—unsatisfactory diet, especially a diet deficient in vitamins; over-indulgence in alcoholic drinks; lack of sufficient exercise or sufficient rest; bad housing conditions or unhealthy conditions of work; and (possibly as important as any other) a lack of wide interests and real zest for life. If we are to fight disease, it is these factors with which we must deal. Over some of them—e.g. bad housing—we as individuals have little control: they must be dealt with by the public health authorities. Others, however, are personal matters.

Public Health

Public health services are an increasing concern of both local and national governments. Control of supplies of food and water so that contamination is prevented, better methods of sanitation and higher standards of civic and personal cleanliness remove many of the ways in which bacteria are spread. Much can be done, also, by eliminating animals which carry disease. Mosquitoes, for example, carry yellow fever and malaria from one person to another as they suck their blood, and by wiping out mosquitoes—as was done in the Panama Canal zone early in this century—these diseases are also eliminated. In the same way, we should prevent the spread of much disease in temperate climates if we could drastically reduce the numbers of rats, mice and flies.

Where infectious diseases do break out, their spread can often be prevented by organising mass-inoculations and mass-gargling and the actual victims of the disease can be isolated in special isolation hospitals. People entering the country from abroad and suspected of carrying infectious disease can be placed in *quarantine*—which is simply another way of saying that they can be isolated so that they cannot pass the disease on to other people.

Quite as important as any of these measures is the problem of providing healthy housing accommodation for the people and—since much ill-health is due indirectly to poverty—the raising of the general standard of living.

Personal Health

We have dealt, in previous chapters, with most of the factors which make for a high standard of personal health and here we need but gather them together in a final summary.

A good wholesome simple diet is one of the foundations of good health (Chapter VI). Civilised man suffers less from adulteration than from over-purification of his food: in the milling of white flour and in the preservation of tinned foods, for example, much of the necessary vitamins and roughage is destroyed or removed. Plenty of green salad and grated raw

vegetables, of cooked green vegetables (not over-cooked), fresh fruit and dairy produce should be included.

Give yourself a chance to digest your food properly. Chew it thoroughly and do not "bolt" it. Eat slowly and do not indulge in strenuous exercise immediately after a meal (p. 146). Keep your teeth in a sound condition by proper methods of feeding, by cleaning them daily and having decaying teeth attended to promptly. Regular visits to the dentist, if possible every six months, will prevent any decay which may start from doing permanent damage to the teeth.

Avoid constipation—it is essential to have a regular motion of the bowels at least once a day—for if the undigested remains of the food stay in the large intestine too long the poisons made by the bacteria there result in a gradual but serious loss of vitality (p. 99).

Drink plenty of water—drinking a glass or two first thing in the morning is a very good habit to cultivate. Take plenty of vigorous exercise (p. 68): if, when you grow up, you have little time or opportunity for regular outdoor exercise and games, perform suitable exercises indoors for a few minutes night and morning. Do not stay up late: "early to bed and a long night's rest" is of especial value to growing boys and girls.

Work and sleep as far as possible in well-aired rooms or in the open air. Take every opportunity of allowing fresh air and sunlight free access to your skin for regular periods (p. 184). Wear light underclothes and put on heavier outer clothing in cold weather: all clothing should be sufficiently porous to allow perspiration to evaporate and escape. Keep thoroughly clean: if possible, have a swim or some sort of bath daily—hot baths are best taken the last thing at night.

Lead a full and vigorous life, in body, mind and spirit, developing interests and activities which will enable you to make wide use of your various talents. Keep your minds open to new ideas and be ready to discuss them with your friends. Follow at least one hobby involving creative work.

These, of course, are merely *general rules*. Living things of the same species differ from one another in at least minute details—no two oak-trees are exactly identical and, again, a good shepherd knows his sheep by noticing their individual

peculiarities. Human beings differ from one another, not only in facial characteristics but in a hundred and one details of constitution. Many of these individual differences have an important bearing on health and only a doctor who knows his patient intimately through regular medical examinations can give the *detailed advice* that we need from time to time. Hence just as we ought to seek to build up health rather than merely strive to escape disease, so we ought to regard our doctors as specialist advisers on questions of health rather than as mere experts in the methods of curing diseases—and consult them periodically for that purpose.

PRACTICAL WORK

1. Put some boiled peas, or a slice of potato, in water and after a few days examine drops of the water with the high power of a microscope. Notice the bacteria present.

2. Examine prepared slides of bacteria.

3. The usual test for the presence of bacteria is to allow them to multiply on jelly contained in a Petri dish (or test-tube) until they have formed colonies large enough to be seen with the naked eye. To prepare the jelly, soak 2 gm. of agar in cold water till it is soft, then pour it into 100 c.c. of warm water and boil carefully (stirring all the while) for 20 min. Sterilise the Petri dishes by leaving them in boiling water for 20 min. and leaving them in the boiled water to cool a little. Pour the hot agar into the dishes (about half filling them), cover them at once and put them aside till the jelly is nearly set. (Test-tubes should be plugged with clean cotton-wool just singed in the bunsen flame.) With such prepared tubes, many experiments are possible, e.g.

(i) Leave one exposed to the air for 10 min.: repeat the experiment after vigorously sweeping the floor.

(ii) Cough, sneeze, or even breathe hard on to the agar surface.

(iii) Rinse the surface of another with saliva diluted with bolled water.

(iv) Take three dishes and rinse their surfaces, one with fresh milk, one with freshly boiled milk, and the third with milk which has been allowed to stand uncovered for a day or so.

(v) On the other surfaces, sprinkle dust from the floor, pockets, etc. Cover the Petri dishes and keep them in a warm place—if possible, in an incubator at about 98° F.—for a day or two. In every experiment leave one test-tube untouched as a control in case the sterilisation has not been perfect.

4. Examine specimens of good and decayed teeth and if possible X-ray photographs and prepared microscope sections of them.

5. Find out what you can about the snake farms (e.g. those of Brazil) at which anti-snakebite serums are prepared.

6. Find out what you can about the work of the Pioneer Health Centre at Peckham. London.

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The numbers in italics (as *17*) refer to figures.